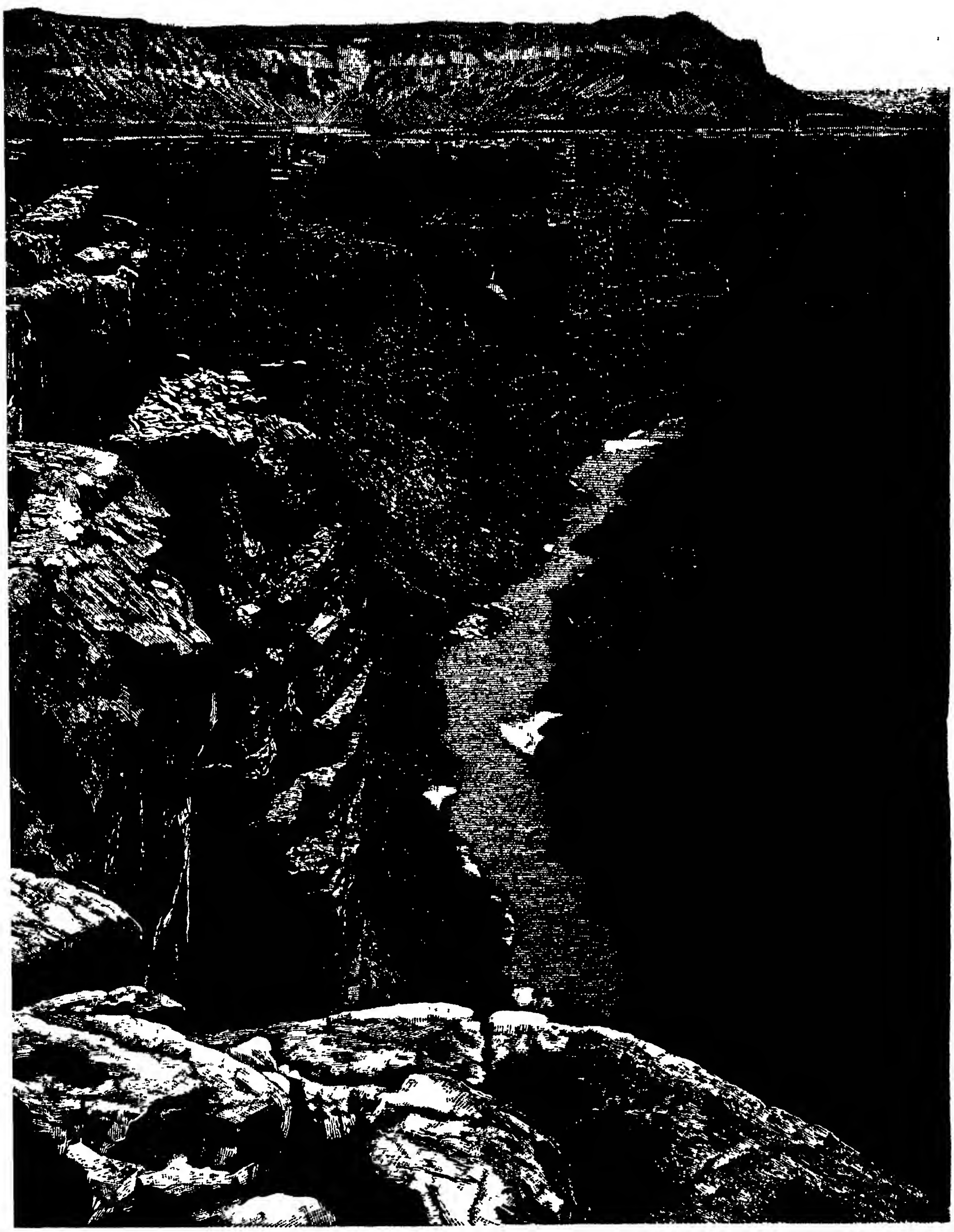
ASPECTS OF THE EARTH



Cañon of the Colorado.

Aspects of the Earth

A POPULAR ACCOUNT OF SOME FAMILIAR GEOLOGICAL PHENOMENA

BY

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ILLUSTRATED

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PREFACE.

The greater part of the several essays contained in this volume have already been printed in *Scribner's Magazine;* the last chapter, that concerning soils, has not been before printed, and to the others considerable additions have been made since they were published.

Something in the way of an apology is due from any writer who, in this day of excessive book-making, reprints papers which have appeared as occasional publications. It may be said in favor of the republication of these essays that, although not originally designed for a book, they were written with a distinct purpose and have a certain common quality. They were intended to give the general reader, unacquainted with the details of natural science, a comprehensible account of some of the more interesting series of the actions which affect the surface of the earth. For this purpose subjects have been selected which, from their nature, commend themselves to the attention of intelligent people. In treating these subjects an effort has been made to show the relation of natural forces to the fortunes of man, and thereby to secure, on the part of the reader, the interest which belongs to matters which affect human welfare alone.

Those long engaged in the study of nature acquire a deep and abiding interest in phenomena, however separated these may be from the ordinary experience of men, or apart from

common subjects of thought. Now and then a youth may be found who, by some odd chance of birth, has almost from the cradle a passion for scientific pursuits; but with most the taste for nature, beyond the mere admiration of the beautiful things of the world, is slowly acquired: they must proceed gradually by way of the matters which are of familiar experience, and in a measure connected with their sympathies, if they are to attain the naturalist's spirit. It is for these very human and fortunately very numerous persons that these essays were written.

Clearly to present the facts of nature to the ordinary reader demands the use of abundant pictorial illustrations. No contrivance in the way of words alone will effect this purpose. In most popular works on science there is an effort to meet this need by diagrams, which at best convey to the mind unfamiliar with the matter an imperfect idea of the facts. It will be observed that all the illustrations in this volume, except in cases where diagrammatic presentation was imperatively required, are taken from photographs, which have been admirably rendered by skilful engravers. In this manner the student has a more faithful presentation of the actual appearance of the phenomena before him than is given in any other work of a popular character which is known to me.

Every teacher who has had occasion to inquire into the state of mind of students, who have begun their study of nature from books in which the ordinary characters of natural phenomena are used for illustrations, has lamented the errors of understanding which such pictures cause. The well-trained engineer can use even rough and sketchy diagrams with profit, for he has a context in mind which serves to complete the conception; but the beginner should have the natural

object which he is called on to consider before him; or if, as is often the case, this cannot be done, he should be provided with the best possible picture of it; a representation which will be reasonably complete without calling on him for any previously acquired knowledge, which he cannot fairly be supposed to possess. From the point of view of the instruction which these essays may afford, the illustrations may fairly be reckoned as the element of most importance in this work.

N. S. S.

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HUMAN society is organized for a stable earth; its whole machinery supposes that, while the other familiar elements of air and water are fluctuating and trustworthy, the earth affords a foundation which is firm. Now and then this implied compact with nature is broken, and the ground trembles beneath our feet. At such times we feel a painful sense of shipwrecked confidence; we learn how very precious to us was that trust in the earth which we gave without question. If the disturbance be of a momentary and unimportant kind, we may soon forget it, as we forget the rash word of a

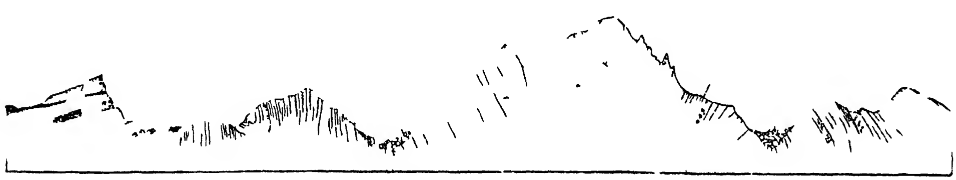
friend; if it be violent, we lose one of the substantial goods of life, our instinctive confidence in the earth beneath our feet.

The notion that the ground is naturally steadfast is an error—an error which arises from the incapacity of our senses to appreciate any but the most palpable and, at the same time, most exceptional of its movements. The idea of terra firma belongs with the ancient belief that the earth was the centre of the universe. It is, indeed, by their mobility that the continents survive the unceasing assaults of the ocean waves, and the continuous down-wearing which the rivers and glaciers bring about.

Were it not that the continents grow upward, from age to age, at a rate which compensates for their erosion, there would be no lands fit for a theatre of life; if they had grown too slowly, their natural enemies, the waves and rain, would have kept them to the ocean level; if too fast, they would lift their surfaces into the regions of eternal cold. As it is, the development has been so well measured to the needs, that for a hundred million years, more or less, the lands have afforded the stage for prosperous life. This uprising, when measured in terms of human experience, is slow; it probably does not exceed, on the average, one foot in three or four thousand years. The rate varies in times and places. Under varying conditions, as when a glacial sheet is imposed on the continent—as it was, in the immediate past, on the northern part of North America—a wide area of the ice-laden land sank beneath the sea, to recover its level when the depressing burden was removed. Still the tendency of the continents is to elevation, and even the temporary sinking of one portion of their area is probably, in all cases, compensated

by uplifts on another part by which new realms of land are won from the sea.

Although access to the deeper earth is denied us, we are probably safe in our belief that this steadfast upward movement of the lands is, in the main. due to a simple cause, which is as follows, viz. : The diameter of the earth depends, in part, upon the amount of heat it contains. This heat is constantly flying out into space. Each moment, from every part of its surface, some portion of the original store escapes into the cold realms of space. With every volcanic eruption a great outrush of heat occurs. Thus, the earth is steadfastly shrink-



Section through Mont Blanc, Switzerland
Showing folds of strata in a mountain.

ing : each age it is girdled by a shorter line. If, by this escape of heat, every part of the earth were equally cooled, there would be no continents, for the whole mass would fall equally toward the centre ; but the deeper parts of the earth lose by far the most heat, for the simple reason that they have the most to part with. The superficial portions long since parted with the larger part of their original caloric.

Thus, this upper portion, or crust, as it is commonly called, does not contract as much as the interior mass, and therefore the inner part tends to leave the outer crust behind. But for the weight of this outer section, it would be left more or less separated from the interior mass ; but, as its weight is much greater than it can sustain, it is compelled to wrinkle, or, in

other words, to form the great ridges and furrows which constitute the continents and the ocean basins. Geologists are still in debate as to the precise manner in which this wrinkling comes about, and as to the way in which it has effected the construction of continents and mountains; but they very generally believe that it is principally due to the cause above mentioned—*i. e.*, to the loss of heat, which is greater from the interior than from the superficial parts of the earth. In a rough way, this folding of the outer part of the earth may be compared to the wrinkling of the skin of a dried apple; only in the fruit the shrinkage of the interior is due to the escape of water, while in the case of the earth it is due to the loss of energy in the form of heat.

It is easy for the reader to see that this wrinkling sets a vast amount of machinery in operation, and compels the movement of masses which cannot be expected to stir without shock. In the upward folding of continents and of mountains, the rocks must bend and break, great fragments of rock must slide over each other, making such flexures as are seen on existing mountains or in regions where mountains have once lifted their ridges, though they may now be worn down to their roots, and no longer have any trace of their original altitude. This folding is titanic work, and the movements at great depths beneath the surface made necessary by this wrinkling demand very extensive disturbances of vast masses of the earth; these uplifted arches of the mountains have to be underpinned, or supported from below, else they would crush down by their own weight; this support from beneath demands the transfer from considerable distances within the crust on either side of the mountain of large quantities of rocky matter. Although this rock is greatly heated, it is probably

not, in a strict sense, fluid, and so moves with a certain difficulty, and only under the compulsion of inconceivably great strains which cannot be expected to act without a certain measure of disturbance. Thus, by the folding, breaking, and slipping involved in the production of the greater reliefs of the earth, a certain amount of sudden and irregular motion is necessarily brought about.

Beneath the sea and along the shores we have another disturbing agent in the volcanic impulse. On the sea-floors the mountain and continent-building forces appear in the main to be wanting, while the volcanic conditions are at rest beneath the interior of the continents. The conditions producing volcanoes appear to originate in the following manner: The deposits of sedimentary matter which are constantly making in the sea-floors contain a great deal of water; from five to twenty per cent. of their mass consists of the fluid which is imprisoned between the grains of mud or sand as the beds are formed. When, in time, any of these beds become deeply buried, they become greatly heated by the heat of the earth's interior, the exit of which is hindered by the strata laid down after the lower beds were formed. When, in this way, a bed is buried to the depth of twenty thousand feet or more, the imprisoned water may be raised to a temperature far above its ordinary boiling point. Into this region of deeply buried water-charged beds the heat comes, not only by conduction from the earth's interior, but also by the action of streams of molten rock, which rush upward from below, forming dykes or veins of lava, such as may often be seen when ancient and once deeply buried strata are disclosed to view by the wearing away of the deposits which formerly lay upon them.

This greatly heated water of the rocks is constantly

seeking to pass into the state of vapor; if it finds any line of weakness, it rends it open, with more than the energy of exploding gunpowder, and forms a volcano. Volcanoes are essentially gigantic explosions, such as are faintly imitated in bursting steam-boilers. In the volcanic explosion the steam is so hot that it may melt the rocks through which it passes, or drive those beds in which it was formed upward to the surface in the form of lavas or finely divided dust.

Thus in the up-growing of the lands to replace the continued down-wearing which assails them, and in the outbreaks of the heated water deeply buried in the sediments derived from these worn lands, we have two evident sources of earthquake movements. These disturbances express themselves on the surface simply as movements, with no distinct evidence as to the origin of the shock; just as, when we hear a loud noise, we may find it to be due to any one of many causes—to a falling meteor, the firing of a cannon, a bursting boiler, or something else in the way of sound-producing action—so with these earthquake shocks: they tell us little of their causation; that is the subject for troublesome and often baffling inquiry. Leaving aside the great slow movements of the lands which we cannot feel, and can only infer from geological monuments, such as ancient shore-lines or the marine fossils in the rocks which compose high mountains, and considering only the sensible movements of the earth's crust, we find several distinct classes of motions by which the earth is affected. Arranging these in the order of their magnitude and the time occupied by their movements, we have the groups noted below.

First among these oscillations of the earth we may notice the slow up or down movements, which are probably of the same general nature and of the same origin as the movements

which build the continents, only much more rapid; so rapid, indeed, that they may be observed from decade to decade, or, at least, from century to century. In this class we include the down-sinking of the coast of New Jersey, the uprising of the northern part of Scandinavia, or the oscillations of the shore on the coast of the Bay of Naples. These movements, which, though in a geological sense rapid, rarely change the level of the land more than a foot or two in a century, appear to be divided into three distinct classes as follows: First, those which are due to the imposition of a heavy weight upon the earth's surface, or to the removal of such a weight. A good case of this is the deep depression of the northern part of North America where the glacial sheet came upon it, and its rapid reëlevation when the ice melted away. Next, those which are due to the formation of a great fault or break through the rocks as they are shoved about by the compressive forces which build mountain chains. And, finally, those which are due to the movements of volcanic gases and the lava which they propel toward the crater, whence, in time, they are to be discharged.

Of these slow movements the most interesting, because the best known, is that which is shown by the ruins of the temple of Jupiter Serapis, near Naples. We see by the evidence of these ruins that the temple has sunk down since the Christian era, so that the marine animals bored into the marble columns at the height of more than twenty feet above the present level of the sea; it then rose up to its original level, and is now again sinking at the rate of one inch in three or four years. A similar movement connected with the process of mountain-building has been observed at Subiaco, about forty miles to the north of Rome. A hundred years or so ago

the church of Jenne was invisible from Subiaco, while now it is in plain view over the summit of the intervening mountain. This change can only be explained by an alteration in the height of the mountain arches of this district.

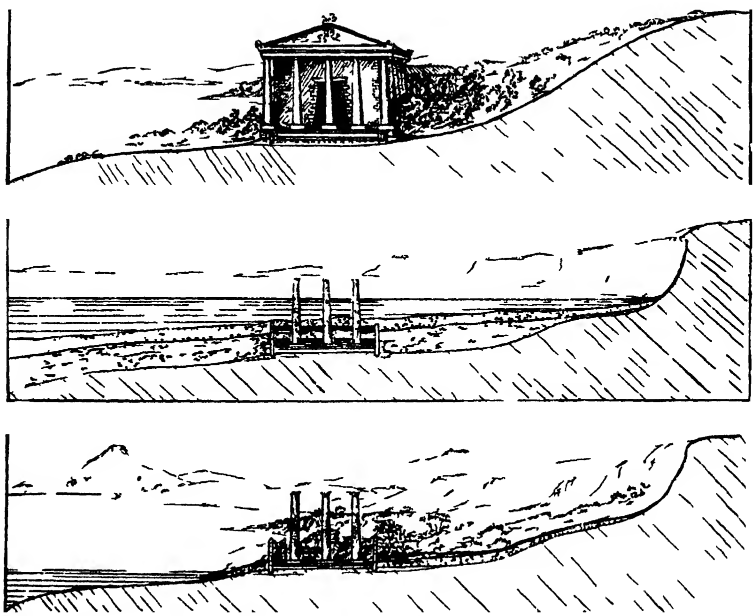


Diagram showing the Geological History of the Temple of Jupiter Serapis *

Along the eastern coast of the United States there are similar gradual changes in the altitude of the lands in relation

* The first figure shows the original position of the temple, the second, the condition at the time of the greatest submergence, the third, the present position of the ruins The reader should observe the changes in the background of these three diagrams Although not intended to depict the details of scenery in an accurate way, a task which would be impossible, they serve to show something of the history of the region Thus, in the uppermost figure, which represents the temple when it was perfect, the background indicates no distinct volcanoes The second diagram is unsatisfactory, for the reason that the shores are shown as higher than in the first figure, while in fact they should be lower In the third picture, the cone on the left hand of the figure indicates the volcanic hill known as Monte Nuovo, which, as will be seen in the text of the chapter on volcanoes, was thrown up in comparatively modern times

to the sea. Thus along the New England coast between New York and Maine, and again along the Gulf of St. Lawrence, we find numerous submerged forests with quantities of trees standing upright, with their roots in old forest beds, but with their crowns some feet below the level of high tide. On the coast of New Jersey, and thence southward to Florida, similar evidence indicates that the marginal part of the continent at least, and perhaps a great portion of its interior area, has gradually sunk down until extensive areas recently land are now submarine. North of New York the continent, at least along the shore line, appears at present to be undergoing slight changes or to be essentially stable; but in New Jersey and along the coast to the southward, there are reasons to believe the down-sinking continues to the present day. It is the opinion of those who have studied the facts in New Jersey that the subsidence is now going on, probably at the rate of two feet in a hundred years, the effect being on this level coast to bring the sea inward with considerable rapidity over the lowlands, thus limiting the area accessible to tillage; at the same time this movement tends to preserve the deep water in the harbors by compensating for the destruction of the depth that comes about through the deposition of alluvium on their floors.

Another class of earth movements includes what have been called by Professor Milne earth pulsations. These are temporary slight swayings of the earth, which, though occupying a short time, from a few seconds to a few hours, are still so slow that they do not give any sense of shock. These swayings of the earth have been best observed by means of delicate spirit-levels, the bubbles of which move with very slight changes of level at either end of the instrument. So

far these observations have been made at but few points and for short periods of time; they serve, however, to show that the surface of the earth is very generally subject to slight oscillations, which probably depend in part upon changes in the weight of the atmosphere; they may, however, in part, be due to the varying strains which are produced by the continent- and mountain-building process, and perhaps, in certain regions near the shore, by the action of the volcanic forces as well.

Another class of movements has received the name of earth tremors. These are very slight jarrings of the earth, too trifling to make any impression on the unaided senses; in fact, only made sensible by means of very delicate pendulums and other contrivances of that nature. Whenever such observations have been carefully undertaken, it has been found that the surface of the earth is in a state of recurrent or continuous movement. In Italy, where these inquiries have been most continually and skilfully made—where, indeed, this branch of geologic study originated—these tremors, though observable at nearly all times, are characterized by fluctuations in their frequency and intensity. During a time of great barometric disturbance the oscillations of the pendulum are often very marked. It seems certain that a cause apparently as slight as the sudden changes in the weight of the atmosphere in the tumult of a gale is sufficient to cause the elastic crust of the earth to tremble. Again, in the days preceding a sensible earthquake, especially one of any violence, the instruments show a great increase in the trembling movement. It appears, indeed, as if in time we may be able to foretell the occurrence of important shocks by their forerunners in the shape of microscopic movements of the earth's crust.

With the microphone, that microscope of the ear, it has been shown that in Italy, and probably wherever these little earthquake waves occur, the earth sends forth a medley of confused sounds—crackings and snappings—probably caused by the rocks creeping toward relief from the strains which urge them to change their position. It is hardly too much to say that this method of observing the earth has enabled us in part to perceive the constant working of the great telluric machinery which continually builds our lands.

Between the class of earth tremors and earthquakes proper there is no other difference, save in the violence of the shock. As long as the movements are imperceptible to the unaided human senses, we, for convenience, place them in the former group; when they are great enough to excite our senses they are called earthquakes.

What has been already said has probably made it clear to the reader that an earthquake shock, like any other jar, is only the result of some disturbance, and not in itself an original fact. In order fully to understand what happens in any shock, it is necessary to look a little more closely at the nature of these vibrations of the rocks which constitute earthquakes. The ordinary experiences of life make us in many ways familiar with the elasticity of common substances; a boy's marble, which is composed either of compact limestone or of glass, though not evidently elastic to a pressure of the fingers, will bounce like a rubber ball if thrown upon a pavement of hard stone. A bullet fired against a stone wall will, as many a boy has noticed, be hurled back with menacing velocity. Such facts show us that if rocks are struck a blow of sufficient violence, they act as very elastic substances. Further experiments, also familiar in the arts, extend this

conception. When a strong blast of gunpowder or other similar explosive is fired, as in quarries or mines, the shock extends for great distances. Thus, in the last great explosion in the mines used for the destruction of the reefs at Hell Gate, near New York, the shock was distinctly perceptible at a distance of more than one hundred miles from the point where the blow was struck, and was possibly evident nearly two hundred miles away.

Returning to the instructive experiment with the marble, we observe that its elasticity is not manifested by a single bounce, but that it again and again rebounds from the stone floor before it comes to rest. This is because gravity impels it downward after each blow sends it up; but if we could suspend the ball in air after its first rebound, we should see that the little sphere vibrated for some time after the blow; we should, under favorable circumstances, see that it simply changed its form from a sphere to a spheroidal shape in a regular pulsating way. If we observe the rocks near a blast discharged in a quarry or mine, our instruments show us that the rock of the earth's crust vibrates in essentially the same manner as the marble—it swings to and fro until the force which set it in motion is exhausted in the frictions which the impulse encounters.

One more peculiar experiment will enable the reader to complete his conception of the important features of earthquake waves. It is easy to remember what happens if we jar the centre of a still basin of water, as we do when we apply a certain amount of force to it by tossing a pebble upon its surface—wavelets are formed, which roll away from the centre. We can easily see that these wavelets are mere wrinkles in the water, created like those we may form in

a strip of carpet when we shake it on the floor. If in their on-going these water-waves strike against any body which does not move with them—a floating cake of ice, for instance—other little waves start back from the resisting objects, which cross and mingle with the original waves and partly destroy them. It is now, we may hope, not difficult to conceive that the waves started in a mass of rock, which are, in a certain general way, like the undulations of the water, may move in any direction from the point where they were created by the jar, until they come to the earth's surface, or are worn out by the frictions which they have to overcome. We also can conceive that diverse accidents in the rocks may much affect the movement of these waves of elastic compression, as they are called, which constitute an earthquake. When the rock is much rifted, they may quickly be extinguished; when it is spongy and inelastic, they may rapidly die away. It is less easy to see that when a vibration is running through rock of a given elasticity, and encounters, as it well may, a kind of rock of another degree of elasticity, it will have its waves reflected, much as those of the pool of water are reflected from a floating cake of ice, and so make a confusion of cross-vibrations, which may very much vary the action of the original movements.

We turn now to consider more in detail the causes of earthquakes. We have seen that the power which urges the continents into their great folds, or the mountains into the lesser corrugations, affords a simple and, indeed, necessary cause of certain violent strains, which in their action tend to compress the rocks into a less bulk than they originally occupied. Under the influence of these strains, any one or more of the following accidents may occur: The rocks may wrinkle

into folds like those we find in mountains; they may be broken along their natural joints or fracture-planes, and the sundered parts may slip over each other, or the rocks may be squeezed out like dough under the cook's roller, and so escape to a region of less pressure. In taking any of these methods of relief, the rocks are necessarily liable to many sudden starts, each accompanied by rendings and other violent movements.

When, in winter, the frozen ground rives asunder, though the crevice is but a small fraction of an inch wide, and a foot or two deep, the ground is often so violently jarred that a sensible earthquake is produced, which may be felt hundreds of feet away from the source of the disturbance. It is, indeed, likely that many of the slight local earthquakes which are chronicled may be due to this cause. We can, therefore, readily see that when the fracture has a length of miles, and a depth of thousands of feet, as is the case in many faults, the jar occasioned may produce a disastrous shock, which may involve a great area of country. But it is not only the rending of the fissures which produces the jar; after the rift is formed the severed masses of rock slip over each other—the rocks on one side rising, while those on the other side slip down.

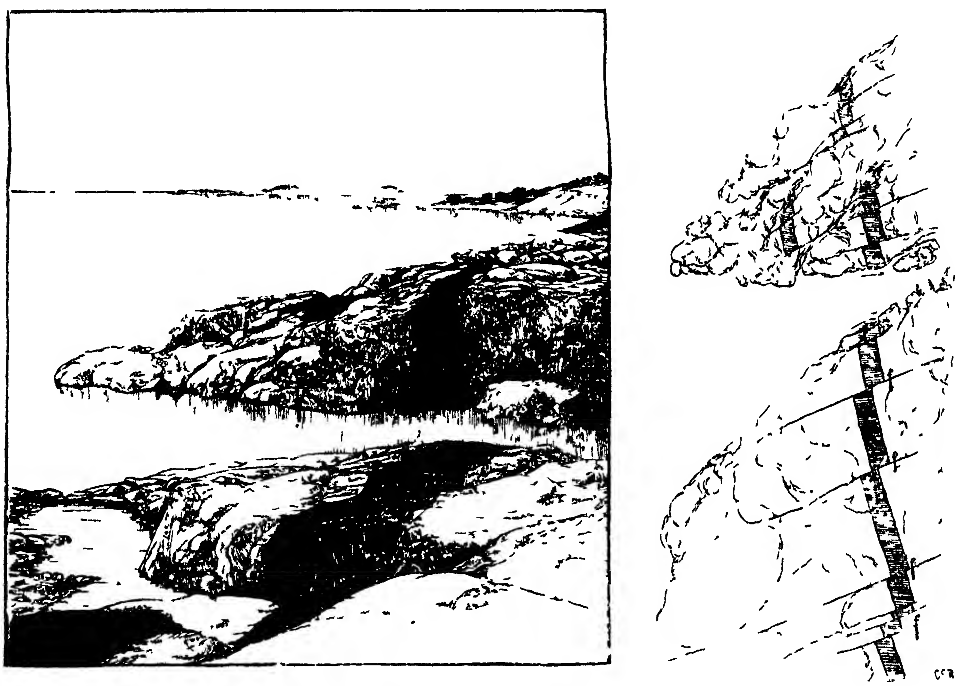
These two great walls on either side of the fault are not smooth, but each is jagged with projections, which are often ruptured as they grind against each other in their opposed movement. By each of these minor rendings, as well as by the formation of the principal fracture, the rocks are set a-quivering like the bounced marble of our previous illustration. These faults are, indeed, earthquake factories. The greatest shock is produced at the time of their formation; but

from time to time they are freshly ruptured, perhaps after a vein deposit has bound their adjacent walls together, and the disturbance is again and again renewed. It is evident that many great faults—those in which the slipping of the sides on each other has amounted to a thousand feet or more—have moved only a few inches at any one time, so that a single such fracture may have given rise to hundreds, if not thousands, of earthquake shocks. So, too, when beds are not broken, but are bent into an arch, the rocks must slip over each other. The reader will see this illustrated if he bends the hundred pages he is reading into a sharp fold. Supposing the pages were from the great stone-book of the earth's crust, and the thickness of each leaf many feet, and of the whole many tens of thousands of feet, it is easy to conceive that the motion would not take place silently, but with much perturbation. There is in mountain-building a chance for many slight shocks, with but a small amount of motion. In the formation of such folds as those of Mont Blanc the tremors may have been numbered by the million.

Another most evident class of shocks have their origin in the movement of rocks which have been melted by volcanic action, and driven on hurried incursions into crevices which are formed in the deep buried parts of the earth's crust. To see the origin of these disturbances, we have only to visit any of those regions of the earth once deeply covered by strata which have been worn away, revealing to us rocks which, by their crystalline structure, indicate their long sojourn in the depths where the volcanic forces are developed.

We find, in almost any region where these crystalline rocks are well exposed to view, many long tongues of lava, which have been violently driven into fissures of the rock,

riving them with destructive power. The formation of such a dyke-fissure and the inrush of the lava must have occasioned a very great jarring of the earth's surface beneath which the movement occurred. If the reader is familiar with the sea-shore, he must often have noticed, in times of storm, the quiver which the stroke of a great wave gives to the rocks



Dyke of Volcanic Rock.

In granite on the shore, in Marblehead, Mass The horizontal plan shows many small faults which have been formed since the dyke was made, each giving rise to an earthquake

when it rushes into some crevice or chasm, and is tossed into spray by the blow. This phenomenon will help him to fancy how great must be the disturbance when a molten lava, three or four times as heavy as water, is driven into the rocks, perhaps with a greater impulse than that which propels the ball from a cannon.

These dykes are, like the faults, inconceivably numerous. All the evidence goes to show that they commonly exist to

the number of hundreds beneath each square mile of the earth's surface. In certain places, the rocks are fairly laced with them.

Leaving out of account the minor sources of disturbance which come from the tumult of volcanic explosions, and the stresses arising from the change in the volume of rocks undergoing alterations in chemical composition, and from loss and gain of heat, we see that in the evident mechanism of the earth we have the natural source of innumerable earthquake shocks. It is almost certain that at one time or another every portion of the earth's surface has felt these disturbances; it is equally clear that the shocks have not at any time been equally common on all parts of the earth's surface, for the reason that the machinery which produces them is often dormant for long periods over large areas. A mountain system, after continuing to grow for ages, may for ages cease to grow—the relief of the pressure which led to its construction being afforded by foldings of the earth's crust at other points, sometimes far away from the original seat of disturbance. So, too, that other class of disturbing actions involved in the formation of dykes appears to be only locally active in any geological period, though in the succession of the ages it probably affects every part of the crust.

In the present condition of the earth's crust, so far as the brief historic record goes to show, earthquakes of an intensity menacing to man are limited to certain regions, which probably do not altogether include more than one-fourth of the area of the lands, though shocks of a less degree of violence appear to be common to every part of the surface of the continents. The regions of recurrent shocks of considerable violence are so irregularly distributed that they cannot be

adequately noted in this brief consideration of the subject. They include, in Europe, Iceland, Portugal, Spain, and Southern Italy; the region of the Lower Danube, and some of the islands of the Grecian Archipelago. In Asia, the larger part of Asia Minor, several limited areas in Hindostan, the greater part of the eastern littoral region of Asia, and the islands of the Japanese and Malayan Archipelagoes are subjected to destructive shocks.

In Africa there is, save in Egypt, little architecture to suffer from earthquake disturbance, and even less history to record it. Egypt seems to have been, on the whole, singularly exempt from great earthquakes, while the western portion of the Mediterranean face of the continent shares the disturbances from which the Spanish peninsula has repeatedly suffered. The vast Australian and Polynesian district of the Pacific affords a number of regions of great earthquake activity, of which New Zealand is the only one where we have anything like good observations for even a few score years. It may be said, however, that the greater part of this vast area seems to be more exempt from these indications of activity in the crust than any other equally extensive part of the earth's surface.

We come now to the twin continents, North and South America. The obvious resemblances in the physical configuration of these continents lead us to expect a likeness in their conditions of stability. This resemblance in a certain measure exists. The western shore of both of these continents, the seaward face of the great Cordilleran range of mountains, is the seat of the most frequent and, on the whole, the most energetic disturbances which occur within their limits, while the eastern shore of each is comparatively little

assailed by shocks. The northern, or Venezuelan, district of South America, which is apparently the seat of an active mountain growth, of which there is no parallel in the northern continent, is a district of recurrent shocks of great violence, such as have never been observed in high latitudes on our own continent. On the other hand, the region from the mouth of the Amazon to the La Plata River, which corresponds to our sea-board Atlantic States and the provinces of Canada, enjoys an immunity from disturbances probably not exceeded by any other equally extensive area occupied by the Aryan race, while the corresponding region in North America is much less fortunate.

It is worth our while to look more closely to the seismic history of North America than we have been able to do in the case of other lands, not alone because of our momentary personal interest, but because it is in the future to be the principal dwelling-place of our race and the home of the type of civilization which that race is developing.

There can be no question that where a people is exposed to recurrent and overwhelming danger, such as menaces the inhabitants of Peru, Venezuela, or Calabria, a danger which as yet is not foretold by science or effectively guarded against by art, the conditions are likely to tell upon its character. "To the firm ground of nature, trusts the hand that builds for aye," is true in a real as well as in a metaphoric sense. This trust in a stable earth is a necessary element in much that is noblest and most aspiring in the life of men. Expose ordinary people to constant devastations from an overwhelming force, whether it be in the form of a human enemy or a natural agent, and their state of mind becomes unfavorable for the maintenance of a high civilization. The best conditions of

society can only be secured when the laborer toils with the assurance that his work will endure long after his own brief life is over.

Care must be taken not to make too much account of the effect exercised by the great convulsions of nature on the moral condition of a people. The need of this precaution is well shown by the social history of Iceland. This country has for the thousand years of its history been subjected to imminent peril from the instability of the earth as well as from the inhospitable nature of its climate. In almost every century of the world's history famine caused by the accidents of the earth and air has menaced the life of the population. Many successive volcanic outbreaks, attended by serious earthquakes, have convulsed this island, and yet amid these mishaps the people have maintained the highest measure of social order in any state of which we have a history. The Icelanders have had the moral strength to rise superior to such afflictions. In this state, as in certain individuals, chastisement which would have destroyed weaker natures served to affirm the vigor of the strong people.

Earthquake shocks may for convenience be divided, according to the violence of the disturbance, into the following classes:

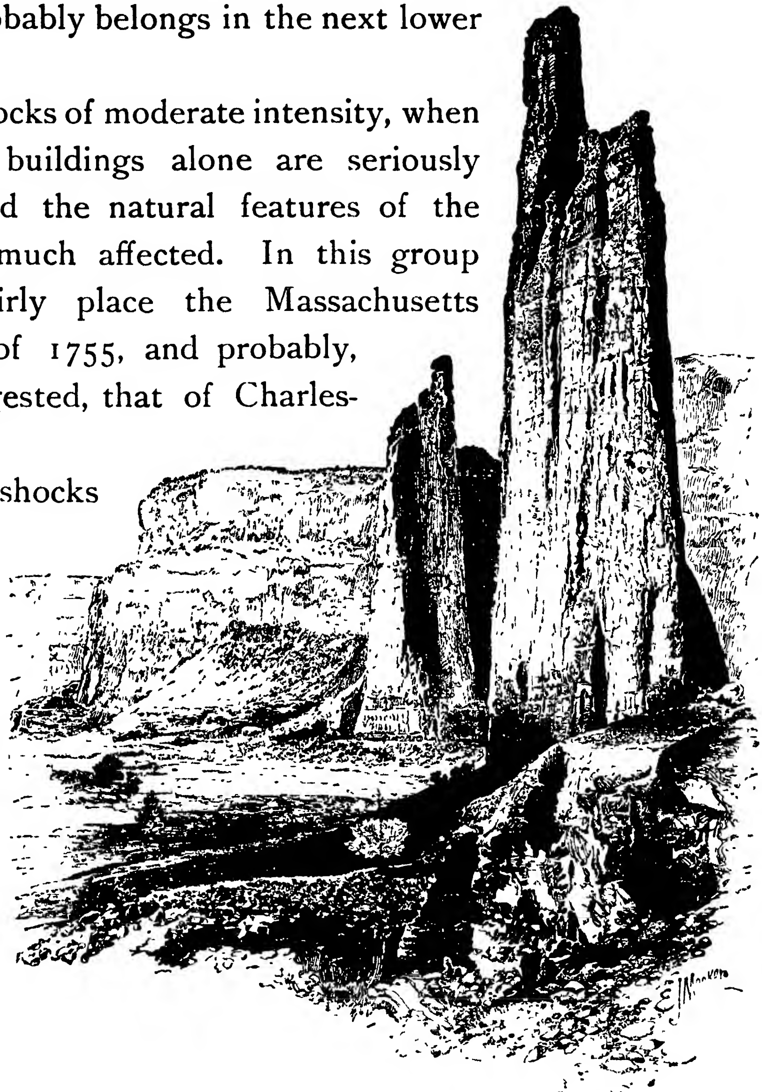
First, the shocks of extreme intensity, in which the most perfectly constructed masonry is destroyed, semi-detached masses of stones along the faces of cliffs thrown down, and the soil-covering of the earth shaken as in a sieve. Of this group the greater earthquakes of Peru and that of New Madrid, Mo., may serve as examples.

Second, shocks of great intensity, in which all but the strongest edifices are overthrown, frail pinnacles of rock over-

turned, and the soil frequently rent by fissures. In this group the earthquake at Charleston in 1886 may find a place, though it probably belongs in the next lower division.

Third, shocks of moderate intensity, when the weaker buildings alone are seriously damaged, and the natural features of the surface not much affected. In this group we may fairly place the Massachusetts earthquake of 1755, and probably, as just suggested, that of Charleston in 1886.

Fourth, shocks distinctly perceptible to the senses, but of slight effect even on weak architecture, and without distinct influence upon the natural features of the earth's surface.



Pinnacled Rocks.

Likely to be overturned by a succession of powerful earthquakes. (U. S. Geological Survey.)

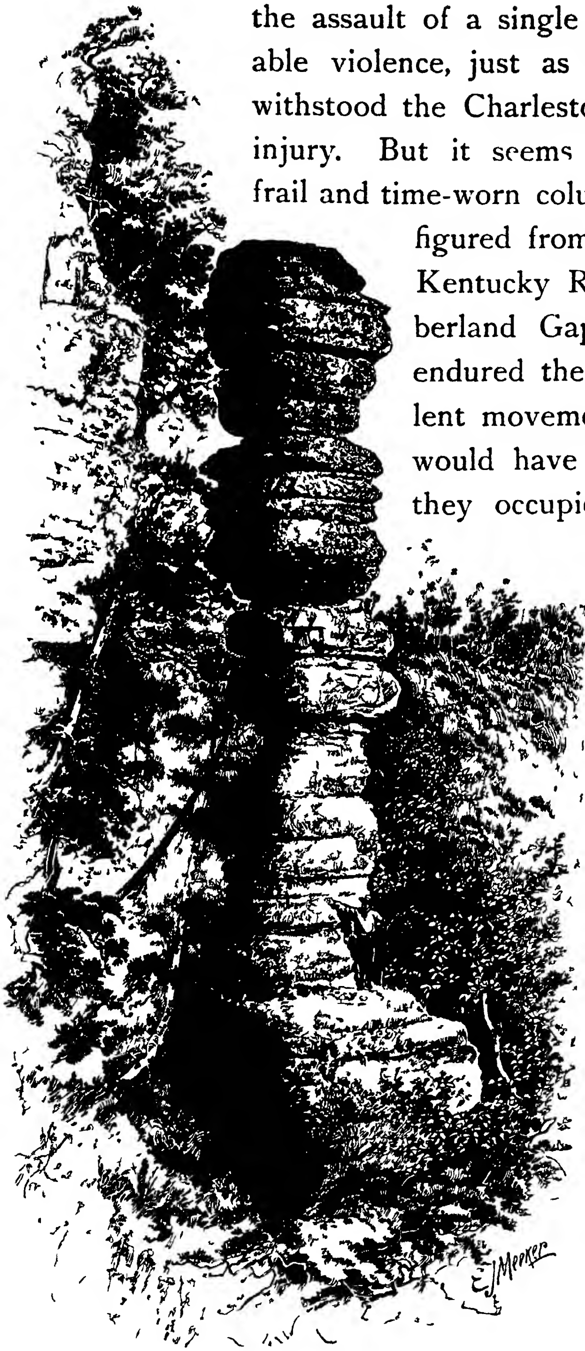
It should be understood that these divisions are merely for convenience of description—in fact, earthquakes form a continuous series, grading from the slightest to the most violent shocks.

In endeavoring to determine the degree to which the different parts of North America have been subjected to devastating earthquake shocks, or to those which would prove disastrous in a country occupied by a complicated society, we find ourselves met with the difficulty which arises from the brevity of our historic records, concerning the greater part of this continent. It is true that in Mexico, and the peninsula district to the southward, we have a record which comprises nearly five hundred years; but of the rest of the continent our longest records are only of about half that duration, and these concern only a little strip of country along the Atlantic coast of the continent; for the remainder the information is for a brief term of a single century. It has occurred to the present writer that it may be possible to supplement this extremely imperfect historical record by an examination of the very numerous poised blocks as well as the detached and frail columns of stone which abound in many districts, natural monuments which would be overturned by a succession of great earthquakes as easily as a Gothic steeple or other frail work of human architecture. Although little has been done with this method of investigation, it will be possible to make some use of it in extending an inquiry which, if it rested on human testimony alone, would be extremely imperfect and unsatisfactory.

These natural indices of a quiet earth have been formed in two different ways, viz.: In the glaciated districts, which practically comprise the northern half of the continent, including all of New England, New York, a great part of Pennsylvania, Ohio, Indiana, and the northern tier of the Western States and Territories, to the Pacific, as well as all the vast territory to the northward of the United States, we

often find perched bowlders, or erratics, left upon the surface at the melting of the glacial sheet. These blocks not infrequently were dropped in positions from which a great earthquake shock would easily dislodge them; occasionally we find a large block which, when the ice melted away, came to be lodged on supporting stones, or on the summit of a rocky hill, in a very insecure position. Yet more often we find a spheroidal block, say two or three feet in diameter, perched on a larger bowlder. In great part these poised stones have been overturned by snow-slides and falling trees; those which escape these mischances have often fallen a prey to boys, who take a natural delight in assisting gravitation to destroy such monuments. In New England and other glaciated districts, the present writer has observed many hundreds of such natural indications of immunity from earthquakes. The other class of these indicators is that of columns or other unstable masses of rock which have been preserved, while the surrounding rock has been worn away, either by the action of rain and streams, or, more rarely, by the beating of the ocean waves when the sea was higher than it is at present. All these pinnacled rocks date from times which, in a historic sense, are very ancient, perhaps hundreds of times as remote as the first written records of this continent. The most of these pillared stones, having a height of twenty feet, may be safely reckoned as of an age of at least twenty thousand years, and thus give us evidence of long-continued immunity from shocks of the first or second order in the districts in which they are found.

It is to be noted that many of the pinnacled rocks, such as are figured in these pages, are much more substantial than they seem, and that they may on that account survive



Erosion Column
From the cañon of the Kentucky River Ky (Ky Geological Survey)

the assault of a single shock of considerable violence, just as detached chimneys withstood the Charleston shock with little injury. But it seems certain that these frail and time-worn columns, such as those figured from the gorge of the Kentucky River or from Cumberland Gap, could not have endured the frequent and violent movements to which they would have been subjected if they occupied a region liable to great earthquakes.

It is true that in those regions where these pinnacles stand as witnesses of a quiet earth, the long dormant movements of the nether world may at any time be awakened. But it is clear that where a region has enjoyed an immunity from violent earthquake shocks during a period of twenty thousand

years or more, we may safely trust it for another millennium. At any rate, the natural evidence, despite its occasional

Pinnacle Rock at Cumberland Gap

Likely to be overturned by a violent earthquake

obscurity, deserves to be taken into account along with the historic record of the earthquakes of any country.

Yet other facts concerning the force with which seismic convulsions have operated during the present geological period in any district may be obtained by the conditions of

the soil on steep slopes. It is a fact well indicated by many observations that a vigorous earthquake serves in all cases to impel the detrital materials, soil or the coarser fragments of decayed rocks, down the slopes on which they are formed. Thus in the great earthquakes of the last century in Jamaica, the steeper slopes of the mountains, though thickly soil covered and forest clad, were hurled down their declivities, so that in a few minutes the mountains were stripped at once of their woods and the materials in which the trees grew, leaving bare rock where before had been luxuriant vegetation.

Wherever we find the soil-coating thickly distributed on slopes having a declivity of more than 30°, we may be sure that the region has been exempt from great shocks during the time when the decomposed materials were accumulating. The soil-coating is in all cases slowly formed. Frost may rapidly break the rock up into angular fragments, but to reduce the rubble to the state of soil requires many thousand years. If, with this general thought in mind, we make a survey of the Appalachian Mountains or the steeper hill-slopes of the Mississippi valley, we become satisfied that the region has been exempt from earthquake shocks of much intensity for many thousand years; combining this evidence with that before referred to, derived from poised bowlders and natural pinnacles, we are able, at least in a general way, to determine the earthquake history of a country for tens of thousands of years in the past.

Proceeding in this way, by combining the natural and the historic evidence, we find that this continent is as diverse as any other of the great land masses in the distribution of the earthquakes of dangerous intensity. Leaving out the districts of Central America and Mexico, where the distribution

of shocks is extremely complicated, and where they are not likely to be a matter of practical importance to our English race, we may advantageously consider, first, the Atlantic seaboard region; then, in succession, the Mississippi valley and the Great Lakes basin, the Rocky Mountain district, and, lastly, the border region of the Pacific.

For our purpose it is necessary to divide the Atlantic seaboard region of North America into a number of districts: First of these is the country north of the St. Lawrence, a district doomed to sterility, where earthquakes might well be allowed to rage, but which appears to be exempt from such disturbances. In the southern part of this region, on the Mingan shore of Labrador, there are many slender columns of rock which attest a long-continued exemption from earthquake shocks.

Next we have the maritime provinces of Canada, which, by the historical as well as the natural evidence, appear long to have enjoyed an equal freedom from severe shocks. Still farther south we have the New England district, extending from the Bay of Fundy to the Hudson. This region, from the natural evidence, appears to have been pretty generally exempt from severe shocks; this evidence is clearest on the coast of Maine, where there are numerous poised bowlders and, on Mount Desert, occasional columnar masses, detached by the action of the sea, where many thousand years ago it stood at higher levels than it does at present. The other parts of New England afford frequent poised blocks, which lead us to the conclusion that the whole of this district has, since the glacial time, escaped severe earthquakes, though the evidence on this point is less conclusive than in the region along the shore to the northward.

It is to be noted, however, that since the settlement of this New England country there have been several shocks of an alarming nature, which have principally affected the State

Steepled Rocks and Erosion Bowlder

Indicating exemption of district from violent earthquakes (U S Geological Survey)

of Massachusetts. That of 1727 and several following years was one of the most peculiar disturbances which have ever been recorded. The first movements of this long-continued series of shocks disturbed a tolerably large area; but in a short time the shocks became confined to the region near the

old town of Newbury, Mass., where from 1727 to 1740 each shock, though the motion was slight, was accompanied by loud and terrifying sounds proceeding from the depths of the earth. We have the story of this strange convulsion from the journal of the Rev. Matthias Plant, the pastor of the Puritan church at Newbury. Although he viewed the matter rationally, many people believed that the tumult was caused by the devil at work in the nether realm.

In 1755, almost coincidently with the great Lisbon earthquake, central New England was visited by a disturbance of considerable violence, one which, though a single shock, was probably nearly, if not quite, as violent as any of the several movements which occurred in South Carolina in 1886. This disturbance, though not hurtful to life or limb, did a good deal of minor damage to the buildings of Boston and vicinity; a good part of the chimneys were overturned, and wherever a heavy weight was supported on a tall, frail base the effects were considerable. John Winthrop, then professor of physics and astronomy in Harvard College, one of the few eminent American men of science of the eighteenth century, states that the bricks from the chimney of his house, in Cambridge, the top of which was thirty-two feet from the ground, were thrown to a point thirty feet from the base of the structure. If we may trust this observation, it is clear that the shock, though not of great violence, was of sufficient force to bring havoc to many flimsy structures of the present day. Since 1755 there has been no earthquake in this district which can be termed menacing in its violence, though movements of slight importance have been numerous.

We may reasonably conclude that while the New England district has probably long been exempt from disturbances of

great severity, the Massachusetts district appears to be liable to shocks of a violence sufficient to wreck buildings which are not well fitted to sustain such assaults.

From the Hudson southward to the James River, and westward to the meridian of Cincinnati, we have a region

Erosion Arch

Showing a type of structure likely to be destroyed by powerful shocks

which, from the natural as well as the historic evidence, we may consider as far free from earthquake action of a dangerous sort as any part of the United States. In this region frail pinnacled rocks and those remnants of old caves, the so-called *natural bridges*, themselves often very frail, abound, and afford good evidence that earthquakes of great force, those which we have classed as of the first and second order, have for many thousand years been wanting in this district. Moreover, the historic evidence goes to show that for two

centuries or so there have been no disturbances of importance in this region.

South of the James River we enter upon the wide lowlands of the Atlantic shore. In this region, owing to the low nature of the topography, there can be none of the natural shock-indicators which we have sought to use in exploring the past history of earthquakes. Parts of this region have been twice shaken with considerable violence—first in the earthquake of 1811, which mainly affected a small area on the borders of the Mississippi, but propagated its waves to this part of the Atlantic sea-board; and again in the Charleston earthquake of 1886. That of Charleston, though in violence not to be compared with the greater shocks of South America, Jamaica, or Central America, was, next to that of 1811, the most violent which within the historic period has ever affected any part of the United States east of the Rocky Mountains. Still it probably should be classed as of the third order in violence. If the edifices of Charleston had been built according to the rules which should guide architects who intend to guard against such calamities, it seems certain that the disastrous consequences of that shock would have been avoided.

The sea-board section of the Gulf States, like that of the Carolinian region, affords us no satisfactory geological evidence as to its earthquake history. But the mountainous region of the southern Appalachians, which is not far removed from this district, abounds in spire-shaped rocks which are delicately poised on their bases, and appear to show that great shocks have long been unknown in those uplands. They especially abound in the valleys in which flow the upper tributaries of the Tennessee River. The greater part of the

Mississippi valley, as far as the natural and historic evidence goes to show, appears to be the seat of but slight disturbances; but in the central portion of that area, from the junction of the Ohio and Mississippi rivers southward, in a region where the natural indices of the earth's stability are wanting, we have the seat of the greatest disturbance that has been recorded on any part of this continent north of the district of the isthmus.

The shocks which affected the Mississippi valley in 1811–13 are, by their violence and continuity, to be ranked among the first score of recorded earthquakes. Save perhaps that which, in 1819, disturbed the delta of the Indus, in western Hindostan, the Mississippi earthquake of 1811 directly produced more extensive and permanent local geographical changes than any other of which we have an account; so violent and continuous were the shakings that the alluvial land in the neighborhood of New Madrid was lowered below its previous level, and into the depressed region the stream of the Mississippi poured in such violence that for a time its lower waters, for a considerable part of their course, turned backward toward their source. Although the colonizing of the district had just begun, the area of country already cleared by settlers which was converted into morasses by the shock was so great that the government was compelled to furnish some hundreds of thousand acres of new lands on higher ground to those whose dwelling-places had been made uninhabitable. It seems likely that an area of not less than five thousand square miles was, on the average, though irregularly, lowered to the depth of ten feet below its original level. The energy of these shocks was so great that the low, strongly built cabins of the pioneers were wrecked, the forest trees

were beaten against each other, and their branches interlocked as they swung to and fro. The irregular movements of the ground led to the formation of numerous great crevices, from which turbid waters were thrown up to a considerable height. To protect themselves from being engulfed in these fissures, the people felled trees so that they lay on the ground at right angles to the general trend of the fissures, and built places of refuge on the broad foundations which they thus secured. There can be no question that a disturbance of this magnitude would, in the present condition of the region where it occurred, cause greater destruction than did that at Charleston.

These two series of disturbances, that of 1811 and 1886, have a close general relation to each other. So alike are they, indeed, as to suggest that the great series of repeated shocks, gradually diminishing in intensity, may be the type of disturbance characteristic of the lowland districts of the southern part of this continent. The New Madrid earthquake of 1811 was, however, by far the more extended phenomenon; the shocks were more frequent and of much greater violence, and the period during which they recurred was far longer than in the Carolinian disturbances.

The peculiar local subsidence of the land which occurred during the earthquakes of 1811 in the alluvial region of the Mississippi valley, as well as similar accidents in other like districts in various parts of the world during earthquake shocks, is probably to be attributed to the fact that in delta regions the frequent changes in the path of the stream form, in the manner described in the chapter on Rivers, numerous lakes in the abandoned portions of the stream-bed. These basins gradually become filled with accumulations of vege-

table matter, and in time are floored over by the river mud, so that all surface indications of the effaced lake disappear. The thick layer of vegetable matter gradually decays, the carbon unites with the oxygen or becomes a gas and escapes to the atmosphere through the porous covering of the earth.

Spring Ho e

Formed during the Charleston earthquakes of 1886 Type of fissure springs formed by earthquakes when the soil is very deep

When this process of decay has gone on for a great period, an earthquake shock causes the mass to settle together, so that the surface may be much lowered. If this view be maintained, we may then find in the great subsidences which occurred in the Mississippi valley during the earthquake of 1811 proof that that shock followed on a very long period of quiet conditions; for if there had been numerous such dis-

turbances in the past, the condensation of the earth would have been previously accomplished. Similar evidence is afforded by the great crevices formed in the Mississippi valley in the earthquake of 1811, and the similar fractures produced in the Charleston shock of 1886, such as are figured on the page opposite. Similar fractures of small size occur in all countries violently shaken by earthquakes, even where such shocks are frequently repeated; but extensive fractures of this sort in a level country would intimate that the region in which they occur had not been disturbed by previous shocks for a great period, perhaps for tens of thousands of years.

North of the Ohio and Missouri rivers we have no historic record of decided seismic disturbances. In Ohio, Indiana, and Illinois the natural evidence is obscure, there being few detached columns of rock which could serve as indices of the past condition of the country. In the district about the upper Great Lakes the natural evidence coincides with the historic record in showing that great disturbances have not occurred in that section. Of the region of the great plains, including Texas, there is no information of much value, though in an indecisive way the topographic evidence is in favor of the conclusion that it has not been seriously shaken for a considerable period.

The topography of the central and eastern section of the Rocky Mountains gives fairly clear evidence that the surface of that region has been, as a whole, tolerably exempt from great shocks. The light rainfall of that part of the continent causes the erosion which produces pinnacled rocks and steep-walled cañons to take place in a much less rapid manner than in the Appalachians; yet parts of this region abound in such

pinnacles, which are evidently very ancient, though often extremely susceptible to strong shocks.

The western coast-line region of the Cordilleras district, from northern California southward to the Mexican line, is more or less subjected to earthquakes of considerable energy, as is shown by historic records. One, in 1812, destroyed a church in Los Angeles, Cal., killing a score or more people. Together with the Charleston earthquake this shock is entitled to a peculiar place in our history; these two shocks being the only earthquakes which have caused any loss of life in this country. There have been several considerable shocks in the region about San Francisco, of which that in October, 1868, caused the overthrow of many frail buildings, and led to precautions in the construction of important edifices which seem likely to insure them from serious accidents.

The vast district of the North American Cordilleras contains so many separate centres of action of the mountain-building and volcanic forces, which have evidently been, in some cases, active in very recent times, that it will not do to extend the conclusions obtained from poised and pinnacled rocks very far from the places where these features occur. It may well be the case that many limited areas in this field are at present liable to shocks of a severe nature.

This brief and unsatisfactory review of the seismology of North America clearly indicates that while the region of the United States and, we may say, of the habitable part of the continent north of Mexico has many districts which are subjected to earthquake shocks of moderate intensity, by far the greater part of its surface shows, within the narrow limits of historic records, no evidence of great seismic dangers, and indicates by its topographical features that it has long been

Crack in the Ground

Produced by the Charleston earthquake of 1886.

preserved from the action of very violent shocks. The only region which we can say has ever been exposed to shocks of anything like the first magnitude is a district probably including an area of not exceeding twenty thousand square miles,

Navaho Church Pinnacled Rocks

Likely to be overturned by a succession of earthquakes of the second order of violence

with its centre about fifty miles below the junction of the Ohio and the Mississippi rivers. Shocks of the second order are almost equally rare; those of California in 1812 and 1868 may have been of this degree of force, but the evidence is too incomplete for accurate determination. Those of the lesser order, but still of a degree calculated to be destructive to

weak architecture, are more common; that of 1755 in New England, several on the Pacific coast, and that of Charleston, S. C., may be placed in this category.

Limiting ourselves to historic evidence alone, we may consider that shocks of the third degree of violence are likely to happen in central New England, the Pacific coast south of Oregon, and in the southern lowlands of the United States, and are probably to be expected in other areas. The natural evidence, though it clearly indicates that the more violent shocks have not been common in the larger part of our territory, does not show that these minor, but still possibly devastating, shocks were wanting.

Although there are no natural monuments in the lowland region of the Mississippi which serve us as proof as to the violence of the seismic power in prehistoric times, there seems to be some evidence to show that the great disturbance of 1811 was exceptional in its nature, and not a frequently recurrent phenomenon in the region where it took place. The remarkable settlement of the soil, which was the most conspicuous feature among the effects of this shock, was probably due to the fact that the alluvial deposits covering the country in which it occurred were, from the circumstances of their formation, very open structured, and became condensed by the shaking to which they were subjected, just as any other loose earth compacts when frequently jarred. If this were the case, and there are many facts to prove it which cannot be discussed here, then we may presume that ages of comparative quiet had gone by during which this unconsolidated alluvial matter was forming, and that ages may again elapse before a similar accident recurs in that region.

We should note the fact that over the surface of the world

in general the great earthquakes do not often sporadically occur, though there are some cases of considerable disturbances which have not been repeated, even after many centuries. Thus the shock which in the year 1185 overthrew the cathedral at Lincoln in England, that which in 1208 in good part destroyed the cathedral at Wells, and that which in 1510 destroyed the town of Nordlingen in Bavaria, are the only historic shocks of great force which have affected the regions in which these accidents occurred. It may, perhaps, reasonably be hoped, though it cannot fairly be reckoned, that the shocks of New Madrid and Charleston were in the nature of such isolated disturbances.

It is satisfactory to find that, within the area of the United States, two centuries of historic record and much natural evidence go to show that great earthquakes are exceptional; but this should not blind us to the fact that large areas are already known to have suffered from movements which may bring wide-spread destruction, where the builder takes no account of any other disturber of stability save gravitation. It is not likely that we as yet know, by experience, the full extent of country which is subject to this order of shocks: our historic perspective is very short, and the natural evidence does not give us any assurance concerning disturbances of this lesser order. It is clear that we cannot, in this country, reckon on an earth as stable as that of the northern region of Europe, where our race was bred and our building system developed. It is equally clear that the mode of construction should be adapted to the new needs which the less firm ground of this country imposes on us.

As long as the building material most commonly in use was timber, and the masonry structures of a low and sub-

stantial nature, they were fairly fitted to afford the resistance required to withstand the shocks which could be expected to come upon them. But the combination of ambition and economy which is filling the land with lofty and flimsy structures invites calamity on the least disturbance of the

Street in Charleston

Showing the relative effect of a moderately strong earthquake on timber and masonry buildings

earth. The shock of 1755, which did little more than stir the fears, shake down the chimney-tops of the old town of Boston, and afford a text for many interesting sermons, would be extremely disastrous to the higher and weaker structures of to-day.

The prescriptions which the architect has to follow in preparing his buildings to resist the strains of a moderate

earthquake are simple, and do not require any great increase in the cost of construction. It is well to understand that the actual movement of the ground, even in violent shocks, is slight. In those which we have termed of the first order it is doubtful if the movement ever amounts to a foot in amplitude, while the shocks which we may anticipate in this country, such as have recently occurred in Charleston for instance, probably swing the earth to and fro within the space of an inch. The destruction is done in part by the suddenness of the to-and-fro motion, which breaks the foundation from the superstructure, but in larger measure by the pendulum-like vibration which is set up in the building. This pendulum movement may cause an oscillation of one inch at the foundations to be several feet in a sixth floor, or say one hundred feet above the ground. The rending effect of this pendulum-like swinging, especially in weak masonry, may easily be imagined.

Many well-considered directions for the protection of buildings from earthquake shocks have been given: of these the best may be found in the excellent, though imperfectly phrased, work on earthquakes by Professor John Milne, of Tokio University, Japan.* From these directions we extract the following, which seem applicable to our conditions:

1. "So arrange the openings in a wall that for horizontal stresses the wall shall be of equal strength for all sections at right angles."

2. "Place lintels over flat arches of brick or stone."

3. "Let all portions of a building have their natural periods of vibration nearly equal."

4. "Avoid heavy-topped roofs and chimneys."

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* "Earthquakes and Other Earth Movements." By John Milne. (International Science Series.) New York: D. Appleton & Co. 1886.

5. "In brick or stone work use good cement."

6. "Let archways curve into their abutments."

7. "Let roofs have a low pitch, and their tiles, especially upon the ridges, be well secured."

It is also important, where the prevailing direction of motion of the shocks is known, to have the blank walls of the house placed so as to be parallel to the course of the shocks. It is also worthy of note that generally hill-tops are more shaken than the ground at the base, for the same general reason that the upper part of a house swings more during a shock than the basement. Last of all, the higher the edifice the more risk of disastrous oscillation and the more need of binding its parts firmly together.

Besides the immediate effect of earthquakes on the surface of the land there are certain secondary consequences, of importance to man, arising from the action of the sea when considerable shocks originate beneath its floor. When a strong disturbance is produced beneath the sea-floor it is propagated for a great distance through the water in exactly the same way as it is through rock. When a ship is near above the point where the earthquake occurs her people feel a sensation as if the vessel had run upon a rock. The vessel may be dismasted or her seams opened by the blow. There are many stories extant which recount the narrow escape of vessels from destruction by these submarine earthquakes, and it seems most probable that many good ships which have disappeared in the deep have been overwhelmed by such calamities.

The most important results of great earthquakes beneath the sea are the broad waves which they produce; waves which may run for thousands of miles before they break upon the shore. We may fairly represent the formation of these waves

by a simple experiment. Taking a flat-bottomed, wide pan, of any sheet metal, partly filled with water, let us strike a sharp, upward blow upon its base. We see that the water rises in the centre and rolls off in a broad circular wave toward the margin. In the seas this wave may have a diameter of some

Effect of a Powerful Earthquake on Massive Masonry Italy

scores of miles, though its height probably never exceeds a few feet. It is so wide and low that as long as it is in deep water it may slip unnoticed beneath a ship; but when the front edge of the wave comes into the shallows near the shore, its advance is somewhat retarded by the friction of the bottom, while the part which is farther out to sea retains

its swift motion. The wave is thus crowded into a less space, and so becomes constantly higher until, when it rushes on the shore, it may have attained a height of fifty feet or more. These waves are, as may be imagined, exceedingly destructive: on the western coast of South America, and elsewhere, they constitute one of the most fearful incidents of great earthquake shocks.

It is a matter for congratulation that the coasts of the United States appear to be exempt from disasters of this nature. Slight movements of the sea, produced in the manner above described, occasionally visit the Pacific shores; but they appear to be derived from shocks which have taken place at great distances from that coast-line. The Atlantic shore of the United States, and indeed the whole shore-line of that ocean north of the Antilles and of Portugal, appear to be free from this danger. The present writer has observed along the rocky portion of the Atlantic shore, from New York to Nova Scotia, a great number of delicately poised blocks, resting at a height a little above the present level of the surf, which clearly indicate that, for a very long period in the past, this coast has been free from such violent incursions of the sea. Similar and even more conclusive evidence, to show the exemption of this shore from these violent invasions of the sea, is afforded by the delicately moulded surfaces of glacial débris which are found just above high water along the Atlantic coast, from New Jersey northward. These curiously combined ridges and pits, termed by geologists *kames*, are almost as frail as footprints on the sand. They could not have survived a single flooding by such resistless waves. Thus the natural as well as the historic evidence points to the conclusion that the North Atlantic sea-bed is not at present the seat of violent earthquakes.

From my own observations, I am inclined to believe that the European coast of the Atlantic Ocean affords sufficient evidence to justify the assertion that marine waves produced by earthquakes have not swept upon the coast in the region north of Spain. Although the evidence is less clear, it is of the same nature as that obtained along the eastern coast of North America, and similarly entitles us to consider this region as exempt from great convulsions of this nature.

We may sum up the foregoing considerations as follows: The continent of North America north of Mexico seems, from historic as well as natural evidence, to be in the main free from any considerable danger of earthquakes which are necessarily destructive to architecture. Nevertheless, a large part of its surface appears to be liable to shocks, which though slight may be very destructive to life and property, if we persist in our present flimsy methods of architectural construction. Good fortune has given us a tolerably safe abiding-place for our race in this country. We can almost everywhere safely put our trust in it, provided we are willing to take some care as to methods of constructing buildings.

When we consider the magnitude of the work done by the subterranean forces, we are impressed with the slight nature of the disturbance by which their activity is manifested to us. It is only in a limited portion of the earth's surface where these disturbances are a serious menace to man. The damage they cause to human life is far less than that brought about by war or preventable disease; and the injury to edifices, though appalling by its suddenness, is on the whole less detrimental than that arising from bad methods of construction.

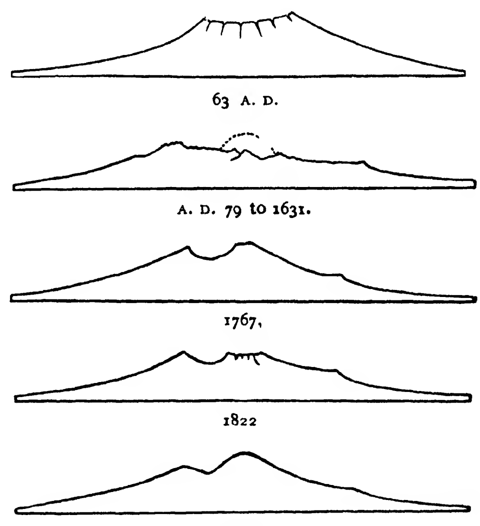
VOLCANOES.

Uniformity of Action of Earth's Machinery.—History of Vesuvius; Period of Greek Settlements; Earthquakes of A. D 63; Eruption of A. D. 79; Story of the Death of Pliny; Changes Produced by this Eruption; Herculaneum and Pompeii; Eruptions after 79.—Present Condition of Vesuvius; Observations on Eruption of 1882; Lessons concerning Volcanic Eruptions from this Eruption. Other Italian Volcanoes.—Icelandic Volcanoes; Eruption of Skaptar in 1783; Effect on Aspect of Sky —Volcanoes about Pacific Ocean: Malayan Volcanoes.—Eruption of Krakatoa in 1883.—Cause of Volcanic Eruptions; Method of Inquiry.—Distribution in Space and Time.—Daubrée's Experiment.—Effect of Accumulation of Strata.—Comparison with Blast Furnace; with Natural Gas Wells.—Evidence from Ætna —Comparison of Lunar and Terrestrial Volcanoes —Effects of Volcanic Action.

THE greater part of the earth's machinery operates in a quiet manner, with something like the order of movement which we associate with the motions of the celestial bodies. Steadfastly, and without violence of a perturbing kind, the continents and mountain-chains rise up, the rivers and seas wear them down, and from age to age the great procession of life moves onward. That man is here to-day as the summit and crown of all the life through which he has come to his present state, is sufficient evidence that the terrestrial powers have never worked with such violence as to throw the delicate mechanism of organic life out of adjustment. If we could conceive the gigantic nature of the forces which act upon and within the earth, this order and harmony of the earth's machinery would appear to be one of its most startling features. It is only in volcanoes that we may see something of the titanic energies of the universe. They alone show us

by what delicate adjustments of strengths and strains this frail mantle of life is enabled to maintain itself on the surface of the sphere.

Although the popular accounts of volcanic eruptions give the general reader some idea of the great energy of these catastrophes, they afford no adequate conception of the nature of the operations which constitute these outbreaks. Still less do they afford him any knowledge of the history of the craters from which these discharges take place. We will, therefore, begin our inquiry with a brief outline of what is known concerning the history of Vesuvius, the one volcano of which we have a tolerably full account for a period of over two thousand years.



Diagrammatic Sections through Mount Vesuvius, showing Changes in the form of the Cone. (From Phillips.)

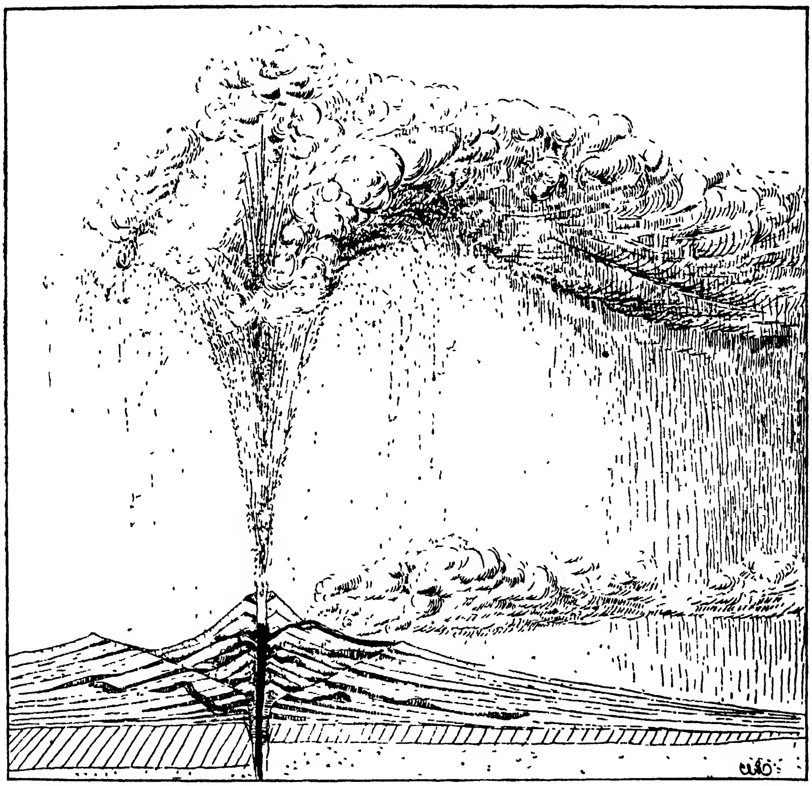
The reader will remember that Vesuvius is situated on the shores of the Bay of Naples. This part of the Italian coast affords excellent harbors, a charming climate, and a fertile soil. Moreover, it has within its broad expanse a number of islands which in the early days afforded admirable strongholds for the small colonies of the Greek folk who for centuries, in a milder way, played the part of the Scandinavians of the later time in the northern seas. The island of Ischia, lying upon the western border of the bay which was in time to receive its name from the relatively modern city of Naples,

was in the fifth century B.C. the first seat of this Grecian settlement. At that time, and for about six centuries afterward, the volcanic cone of Vesuvius was not in activity and had a very different aspect from that it has in the present day. It was, as is shown in the cut on the preceding page, a broad, low mountain, not rising more than two thousand feet above the level of the sea. The crater was deep and wide, and to a modern eye would have told its volcanic history by its form; but this history had not been unravelled, and to the people of that time it was a hill and nothing more.

During the long sleep of Vesuvius the settlers on Ischia were afflicted with very serious eruptions from the craters on that island, and at one time were driven away from their settlements by these disasters. In this period, while Vesuvius was at rest, there were perhaps other slight eruptions of volcanic gases in the country west of Vesuvius known as the Phlægrean Fields. It is now evident that the pent-up volcanic powers were struggling to open another way for their exit. They were, however, so unsuccessful that the country remained for centuries but little disturbed. It became the country-seat of the wealthy Roman citizens, who found there exemption from the distractions of the capital. Around Vesuvius itself, along the shore of the bay, and on the vine-clad slopes of the mountain, there were wealthy towns, temples, baths, and all the other rich constructions of that architecture-loving people, the Romans. Except for the eruptions in Ischia, which was sufficiently remote from the mainland to make its disturbances of no great importance, this Vesuvian district enjoyed an undisturbed tranquillity down to the year 63 of our era. In that year there began a series of moderately strong earthquakes produced by the volcanic gases in their

struggle to reopen their long-closed passages to the crater. In August, 79, these subterranean movements became more and more violent until they terminated in a furious eruption.

We gain all our knowledge of the circumstances of this great catastrophe from the letters of the younger Pliny to the



Diagrammatic Section through Vesuvius, in Time of Eruption, showing the General Form of the Vapor-column and the Falling Ashes and Rain.

The lower cloud of steam is from lava-flows. The lower cup of the crater is that formed before the Christian era.

historian Tacitus, in which that writer gives an account of the death of his uncle, the naturalist Pliny, who lost his life during the eruption. The elder Pliny was admiral of the Roman fleet stationed in the port of Misenum, now known as Baiæ, on the western shore of the bay. The eruption began about mid-day, and in a short time the whole of the eastern side of the

bay was hidden by the vast cloud of steam, commingled with finely pulverized dust, which constitutes the so-called smoke of a volcanic eruption. Gradually this cloud extended, until it brought the darkness of night over all the area within twenty miles of the volcano, and a wide field beyond, extending its shadow, according to Dion Cassius, over Africa, Syria, and Egypt.

The letters of the younger Pliny were designed not to give a detailed account of the eruption itself, in which the writer seems to have had none of the inquirer's interest which led his uncle to his death, but to give Tacitus information as to the last hours of the great naturalist. His account affords, however, though incidentally, a picturesque description of the catastrophe, as seen by a cultivated Roman youth of eighteen years. Notwithstanding the beauty of their style and their charming simplicity, the letters of the younger Pliny are but little known to the public, even in translation. I therefore give the greater part of the two which refer to the eruption, omitting those portions which contain the compliments in which Roman correspondents were wont to indulge. This translation I owe to my friend, Professor J. G. Croswell, who has given a better and more lively rendering of the text than can be found in any of the previous versions.

[PLINY'S LETTERS. BOOK VI., 16.]

Gaius Plinius sends to his friend Tacitus greeting.

You ask me to write you an account of my uncle's death, that posterity may possess an accurate version of the event in your history. . . .

He was at Misenum, and was in command of the fleet there. It was at one o'clock in the afternoon of the 24th of August that my mother called his attention to a cloud of unusual appearance and size. He had been enjoying the sun, and after a bath had just taken his lunch and was lying down to

read ; but he immediately called for his sandals and went out to an eminence from which this phenomenon could be observed. A cloud was rising from one of the hills (it was not then clear which one, as the observers were looking from a distance, but it proved to be Vesuvius), which took the likeness of a stone-pine very nearly. It imitated the lofty trunk and the spreading branches, for, as I suppose, the smoke had been swept rapidly upward by a recent breeze and was then left hanging unsupported, or else it spread out laterally by its own weight, and grew thinner. It changed color, sometimes looking white, and sometimes, when it carried up earth or ashes, dirty and streaked. The thing seemed of importance, and worthy of nearer investigation, to the philosopher. He ordered a light boat to be got ready, and asked me to accompany him if I wished ; but I answered that I would rather work over my books. In fact he had himself given me something to write.

He was going out himself, however, when he received a note from Rectina, wife of Cæsius Bassus, living in a villa on the other side of the bay, who was in deadly terror about the approaching danger and begged him to rescue her, as she had no means of flight but by ships. This converted his plan of observation into a more serious purpose. He got his men-of-war under way, and embarked to help Rectina, as well as other endangered persons, who were many, for the shore was a favorite resort on account of its beauty. He steered directly for the dangerous spot whence others were flying, watching it so fearlessly as to be able to dictate a description and take notes of all the movements and appearances of this catastrophe as he observed them.

Ashes began to fall on his ships, thicker and hotter as they approached land. Cinders and pumice, and also black fragments of rock cracked by heat, fell around them. The sea suddenly shoaled, and the shores were obstructed by masses from the mountain. He hesitated awhile and thought of going back again ; but finally gave the word to the reluctant helmsman to go on, saying, "Fortune favors the brave. Let us find Pomponianus." Pomponianus was at Stabiæ, separated by the intervening bay (the sea comes in here gradually in a long inlet with curving shores), and although the peril was not near, yet as it was in full view, and as the eruption increased seemed to be approaching, he had packed up his things and gone aboard his ships ready for flight, which was prevented, however, by a contrary wind.

My uncle, for whom the wind was most favorable, arrived, and did his best to remove their terrors. He embraced the frightened Pomponianus and encour-

aged him. To keep up their spirits by a show of unconcern, he had a bath ; and afterwards dined, with real, or what was perhaps as heroic, with assumed cheerfulness. But, meanwhile, there began to break out from Vesuvius, in many spots, high and wide-shooting flames, whose brilliancy was heightened by the darkness of approaching night. My uncle reassured them by asserting that these were burning farm-houses which had caught fire after being

View in Pompeii, looking Northwest, showing the Unexcavated Portion on the Right Hand, and in the Distance the Present Cone of Vesuvius, on its Right a Portion of Prechristian Crater-wall.

deserted by the peasants. Then he turned in to sleep, and slept indeed the most genuine slumbers ; for his breathing, which was always heavy and noisy, from the full habit of his body, was heard by all who passed his chamber. But before long the floor of the court on which his chamber opened became so covered with ashes and pumice that if he had lingered in the room he could not have got out at all. So the servants woke him, and he came out and joined Pomponianus and others who were watching. They consulted together as to what they should do next. Should they stay in the

house or go out of doors? The house was tottering with frequent and heavy shocks of earthquake, and seemed to go to and fro as if moved from its foundations. But in the open air there were dangers of falling pumice-stones, though, to be sure, they were light and porous. On the whole, to go out seemed the least of two evils. With my uncle it was a comparison of arguments that decided; with the others it was a choice of terrors. So they tied pillows on their heads by way of defence against falling bodies, and sallied out.

It was dawn elsewhere; but with them it was a blacker and denser night than they had ever seen, although torches and various lights made it less dreadful. They decided to take to the shore and see if the sea would allow them to embark; but it appeared as wild and appalling as ever. My uncle lay down on a rug. He asked twice for water and drank it. Then as a flame with a forerunning sulphurous vapor drove off the others, the servants roused him up. Leaning on two slaves he rose to his feet, but immediately fell back, as I understand, choked by the thick vapors, and this the more easily that his chest was naturally weak, narrow, and generally inflamed. When day came (I mean the third after the last he ever saw) they found his body perfect and uninjured, and covered just as he had been overtaken. He seemed by his attitude to be rather asleep than dead.

In the mean time, my mother and I at Misenum—but this has nothing to do with my story. You ask for nothing but the account of his death. . . .

[BOOK VI., 20.]

Gaius Plinius sends to his friend Tacitus greeting.

You say that you are induced by the letter I wrote to you, when you asked about my uncle's death, to desire to know how I, who was left at Misenum, bore the terrors and disasters of that night, for I had just entered on that subject and broke it off. "Although my soul shudders at the memory, I will begin."

My uncle started off and I devoted myself to my literary task, for which I had remained behind. Then followed my bath, dinner, and sleep, though this was short and disturbed. There had been already for many days a tremor of the earth, less appalling, however, in that this is usual in Campania. But that night it was so strong that things seemed not merely to be shaken, but positively upset. My mother rushed into my bedroom. I was just getting up to

wake her if she were asleep. We sat down in the little yard, which was between our house and the sea. I do not know whether to call it courage or foolhardiness (I was only seventeen), but I sent for a volume of Livy, and, quite at my ease, read it, and even made extracts, as I had already begun to do. And now a friend of my uncle's, recently arrived from Spain, appeared, who, finding us sitting there and me reading, scolded us, my mother for her patience, and me for my carelessness of danger. None the less industriously I read my book.

It was now seven o'clock, but the light was still faint and doubtful. The surrounding buildings had been badly shaken, and though we were in an open spot, the space was so small that the danger of a catastrophe from falling walls was great and certain. Not till then did we make up our minds to go from the town. A frightened crowd went away with us, and as in all panics everybody thinks his neighbors' ideas more prudent than his own, so we were pushed and squeezed in our departure by a great mob of imitators.

When we were free of the buildings we stopped. There we saw many wonders and endured many terrors. The vehicles we had ordered to be brought out kept running backward and forward, though on level ground; and even when scotched with stones they would not keep still. Besides this, we saw the sea sucked down and, as it were, driven back by the earthquake. There can be no doubt that the shore had advanced on the sea, and many marine animals were left high and dry. On the other side was a dark and dreadful cloud, which was broken by zigzag and rapidly vibrating flashes of fire, and yawning showed long shapes of flame. These were like lightnings, only of greater extent. Then our friend from Spain attacked us more vigorously and earnestly. "If your brother, your uncle," said he, "is alive, he wishes you to be safe; if not, he certainly would wish you to survive him. Why, then, do you delay your flight?" We said we could not bring ourselves to think of our own safety while doubtful of his. So, without more delay, the Spaniard rushed off, taking himself out of harm's way as fast as his legs would carry him.

Pretty soon the cloud began to descend over the earth and cover the sea. It enfolded Capreæ and hid also the promontory of Misenum. Then my mother began to beg and beseech me to fly as I could. I was young, she said, and she was old, and too heavy to run, and would not mind dying if she was not the cause of my death. I said, however, I would not be saved with-

out her; I clasped her hand and forced her to go, step by step, with me. She slowly obeyed, reproaching herself bitterly for delaying me.

Ashes now fell, yet still in small amount. I looked back. A thick mist was close at our heels, which followed us, spreading out over the country, like an inundation. "Let us turn out of the road," said I, "while we can see, and not get trodden down in the darkness by the crowds who are following, if we

View of Excavated Portion of Pompeii, looking Northwest
Shows, on either side, the depth of the ash covering Vesuvius in the distance.

fall in their path." Hardly had we sat down when night was over us—not such a night as when there is no moon and clouds cover the sky, but such darkness as one finds in close-shut rooms. One heard the screams of women, the fretting cries of babes, the shouts of men. Some called their parents, and some their children, and some their spouses, seeking to recognize them by their voices. Some lamented their own fate, others the fate of their friends. Some were praying for death, simply for fear of death. Many a man raised his hands in prayer to the gods; but more imagined that the last eternal night

of creation had come and there were now no gods more. There were some who increased our real dangers by fictitious terrors. Some said that part of Misenum had sunk, and that another part was on fire. They lied ; but they found believers.

Little by little it grew light again. We did not think it the light of day, but a proof that the fire was coming nearer. It was indeed fire, but it stopped afar off ; and then there was darkness again, and again a rain of ashes, abundant and heavy, and again we rose and shook them off, else we had been covered and even crushed by the weight. I might boast of the fact that not a groan or a cowardly word fell from me in all the dreadful peril, if I had not believed that the world and I were coming to an end together. This belief was a wretched and yet a mighty comfort in this mortal struggle. At last the murky vapor rolled away, in disappearing smoke or fog. Soon the real daylight appeared ; the sun shone out, of a lurid hue, to be sure, as in an eclipse. The whole world which met our frightened eyes, was transformed. It was covered with ashes white as snow.

We went back to Misenum and refreshed our weary bodies, and passed a night between hope and fear ; but fear had the upper hand. The trembling of the earth continued, and many, crazed by their anxiety, made ludicrously exaggerated predictions of disaster to themselves and others. Yet even then, though we had been through such peril and were still surrounded by it, we had no thought of going away till we had news of my uncle. . . .

It is evident that this eruption produced great changes in the surface of all the country about Vesuvius. Although no lava-streams flowed from the crater, for the reason, as we shall hereafter see, that the eruption was so violent as to prevent their formation, the quantity of molten rocky matter which was blown into fragments and fell mainly in the form of dust upon the surface of the earth about the crater was enormous. For a distance of several miles from the vent, this accumulation seems to have attained the depth of ten to thirty or more feet. Owing to the extreme lightness of this dust, which is pumiceous, or filled with air-bubbles, the greater part of the

deposit has probably been washed away by the rain, as have the lesser ash-showers of later years. At the close of the eruption of Pliny, this dust probably covered the ground to a far greater depth than is indicated by the scanty remains of the great shower which still exist on the surface. On no other supposition can we account for the abandonment of the two cities of Pompeii and Herculaneum, which were so far lost that no tradition as to their position remained. Both of these cities were probably stripped of their more precious treasures before they were covered with the ash, and the mud which was formed of it by the torrential rains ; still so much that was valuable was left behind, that we can hardly conceive how the dispossessed people should have failed to dig for the treasures, unless they were deterred by a thicker sheet of *débris* than now remains upon Pompeii.

At the close of this eruption the surface of the country immediately about Vesuvius must have been a waste of ashes. Besides the two important towns of Herculaneum and Pompeii, there were, it may be, scores of villages which were buried in the same way. It is not likely that the loss of life in this catastrophe was very great. It was some hours before the eruption became of fatal violence, and nearly all the inhabitants, save the sick and prisoners, found safety in flight. Of the hundred or so skeletons which have been found in the excavation at Pompeii, some appear to be the remains of soldiers, who, receiving no orders to withdraw, met death in their appointed places. Occasionally as the explorers are removing the firmly cemented ash from the cellars of a house, their picks penetrate a cavity. Experience has shown that these spaces are generally moulds which the wet ashes formed about a prostrate human body. By pouring plaster-of-Paris into the

empty places, it has been found possible to obtain accurate casts of the long-vanished forms.

The eruption of the year 79 was followed, as is usual after great eruptions, by a long period of repose. The next outbreak of the volcano was in the year 203, and appears to have been of moderate violence. After another equally long

A Lava stream Overwhelming a Town on the West Side of Vesuvius

pause, in 472 there was an extremely violent eruption, which is reported to have scattered ashes over nearly all Europe, and so darkened the sky at Constantinople, about eight hundred miles away, that the Emperor Leo fled from the city, and for a long period thereafter the deliverance of the town was celebrated by an annual festival. Thence to the year

1036 of our era we have records of occasional slight eruptions, but, as the reader knows, this was the night-time of history, and the chronicles are very imperfect. In 1036 it seems tolerably clear, from an ancient itinerary, that lava flowed from the cone to the sea. This appears to have been the first eruption during the historic period in which lava flowed from Vesuvius, though in the prehistoric period of the mountain's activity it was abundantly produced.

From this eruption onward to modern times we have an excellent catalogue of the eruptions of both Vesuvius and Ætna, which, curiously enough, we owe in good part to the superstitious notion that the outbreaks may be stopped by the intercession of the patron saints of the country. Whenever an eruption occurs the priests who guard the relics of St. Januarius, in Naples, or of St. Agatha, in Sicily, address these patrons of their respective cities through their relics, vestments, or images. If the eruption speedily diminishes in violence, as from the nature of its action it must always do, the amendment is attributed to the influence of the saintly power, and the fact, with date and circumstance, is a matter of careful record.* Thus science has come to owe a considerable debt to superstition. Although this picturesque relation adds a certain interest to the chronicles of the eruptions of Vesuvius, we need not weary the reader with them, but sum up the record in brief. In short, the story is that from 1036 to 1500 there were five eruptions, or about one each century, and none of them of great violence. It seems, indeed, likely that from 1139 to 1631 there were at most slight threats of

* See "Vesuvius" (page 45), by John Phillips. Clarendon Press, Oxford, 1859. From this valuable work I have condensed the above statements concerning this volcano.

activity, and that the internal pressure was not relieved until the great explosion of the last-named year.

The eruption of 1631 was, next after that of 79, the most violent explosion which has taken place from Vesuvius. Like the eruption in which Pliny met his death, the disturbance was ushered in by a succession of earthquake shocks. These shocks, due doubtless to the struggle of the imprisoned gases with the barriers which the earth interposed, grew more and more violent, until, on December 16, the outbreak began suddenly and with extreme fury. Unlike most eruptions from this and other craters, where the flow of liquid rock usually begins some time after the gases break forth, a great tide of lava at once burst forth from the side of the cone, at some distance from the summit of the crater. The streams rushed forth from a number of points along the southwest slope of the mountain, at a height of about three thousand feet above the sea, and swept down toward the shore of the bay. Although a large part of this lava remained in the depressions in the flanks of the mountain, a dozen or more of the streams which diverged from the great sheet attained the sea along a length of seven and a half miles of the shore. Then, as now, the coast was bordered by an almost continuous line of populous towns. Although the inhabitants had fled in great numbers, moved by the fear with which the earthquakes and roarings from the mountain inspired them, the lava-flow came so suddenly that eighteen thousand persons perished in the towns of Resina, Torre del Greco, and Granatello, which were overwhelmed by the streams. The ash, or finely divided lava, was blown forth in prodigious quantities, once again darkening the skies as far to the east as Constantinople. The rain which fell from the cloud

which hung over all the region about the mountain was torrential; mingled with the fine dust, it produced vast inundations of mud, which swept over the fields and villages, producing destruction more wide-spread, if less disastrous to life, than the streams of fiery lava. In this, as in all the

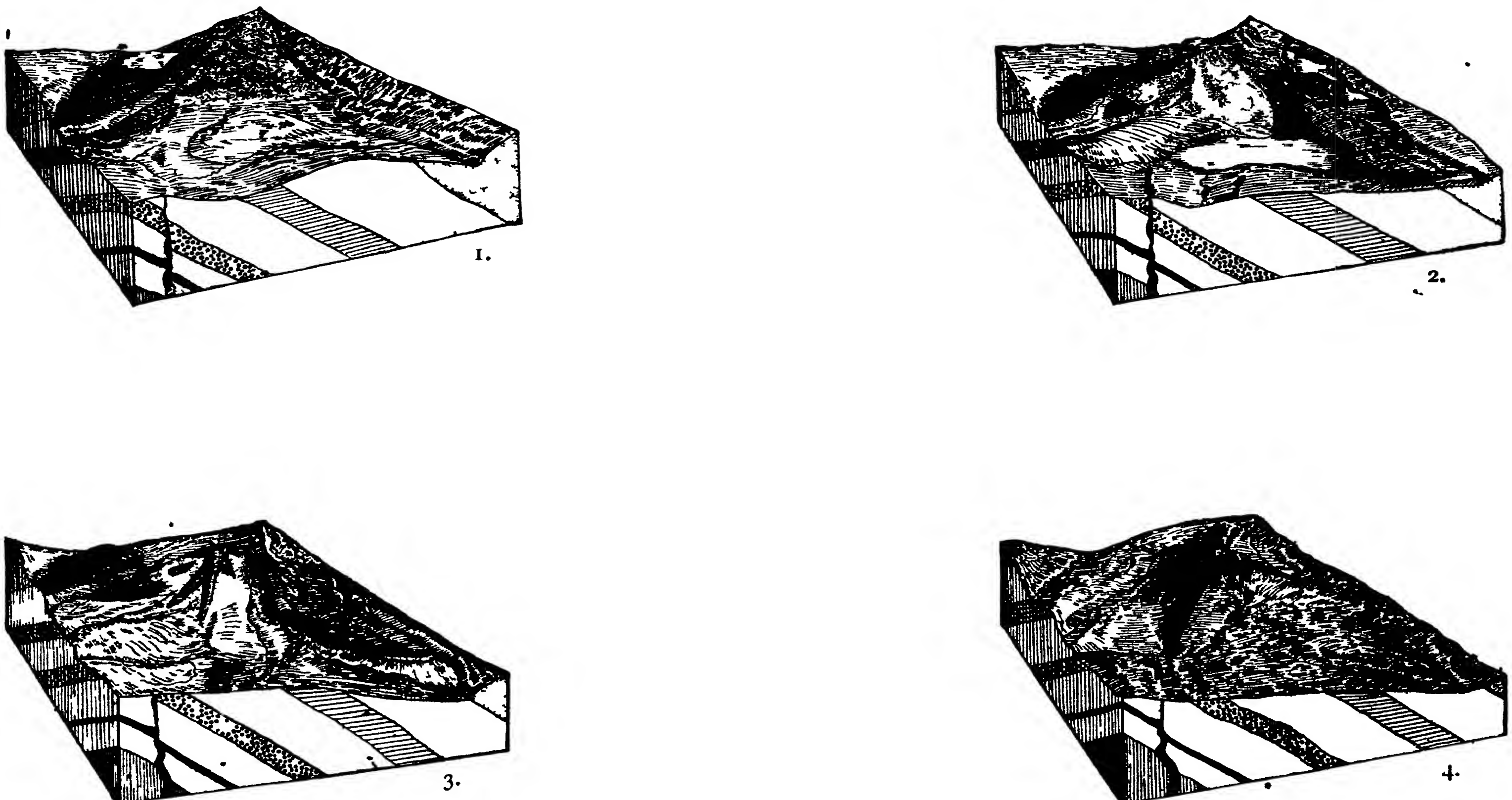
Vesuvius, Near View of the Small Inner Cone of the Crater showing Recent Undecayed Lava on which Rests the Ash-heap of the Cone

great eruptions, the lightning from the clouds was extremely violent and caused much loss of life.

From the time of this disaster down to the present day the eruptions have been more frequent than in any other part of the volcano's history. Rarely have twenty years passed without an outbreak of considerable violence, though none of them have attained to the appalling fury of the first historic outbreak or that of 1631. Near four-score eruptions are

chronicled in this period of about two and a half centuries; nearly all of them have been of moderate intensity, but have led to a singularly large extrusion of lavas. It is evident that the channels which lead to the rents of the volcano are now gorged with fluid lava; wherever the pressure of the imprisoned gases becomes strong enough this lava is forced up into the crater, by its weight rends open the walls of incoherent cinders, and escapes upon the steep slopes of the cone.

Many of these outbreaks are of very slight energy. It was the present writer's good fortune to obtain an unusually near view of the beautiful little eruption of the winter of 1882, which afforded a singularly good opportunity for watching the essential processes of volcanic explosions with little danger. At this time, from the slight violence of the outbreak, the crater was reduced to a small depression near the summit of the cone, which had a diameter of not over six hundred feet and a depth of about one hundred feet. Taking advantage of a strong gale from the north, the well-known *tramontana* of Italy, it was possible to creep up to the very edge of this crater and look down upon the surface of the boiling lava, from which the gases were breaking forth. Although the pit was from time to time filled with whirling vapor, the favoring wind often swept it away so that for a few seconds it was possible to see every feature of the terrifying scene. Several times a minute the surface of the tossed lava was rent by a violent explosion of gases, which appeared to hurl the whole mass of fluid rock into the air. The ascending column of vapor and lava fragments rose as a shaft to the height of several hundred feet. Many of the masses, which seemed to rise with the ease of bubbles, were some feet in



Four Stages of a Volcanic District (From series of school-models by N S Shaler and W M Davis)

1 Two new lava-cones Lava-stream partly blocking a valley, forming a lake
2 Smaller cone grown to be the larger, its lava blocking two other valleys, the first lake drained
3 Volcanoes extinct, the cones wearing away, showing their roots, new valleys forming, lakes drained, obstructing lavas taking the form of hills
4 Volcano and lavas destroyed nothing remaining but the dikes at the old base of the cone to mark its former presence

A study of the lines indicating strata will show the rate of downwearing

diameter, and made a great din as they crushed down upon the surface on the southward side of the crater. They often could be seen to fly into fragments as they ascended. At the moment of the explosion the escaping gases appeared transparent, a few score feet above the point of escape the ejected column became of a steel-gray color, and a little higher it changed to the characteristic hue of steam. That it was steam slightly mixed with other gases was evident wherever in its whirling movements the vaporous column swept around the point of observation. The curious "washing-day" odor of steam was perfectly apparent, together with a pungent sense of sulphurous fumes suggestive of an infernal laundry.

Although the heat at the moment of explosion was great, it was possible, with the shelter to the face secured by an extemporized mask, to avoid any serious consequences from it, and even to make some rather rude and unsatisfactory diagrams of the scene. The principal obstacle to observation arose from the violence of the shocks given to the cone and propagated through the air by the explosions, which made it extremely difficult to fix the attention on the phenomena. The earthquakes attending each explosion were almost strong enough to shake one from the ground, and the blow received through the air was like that which those familiar with mines have felt when a heavy charge of gunpowder or dynamite is exploded. The sensation is such as might come from being violently struck by a feather bed; not dangerous, but extremely disorganizing to the wits. After about fifteen minutes of observation a slight change of the wind allowed the descending masses to fall so near the point of view that it was necessary to hurry away.

As if to complete the illustration of volcanic phenomena

which this little outbreak afforded, there was a small rivulet of lava pouring from the low wall of cinders on one side of the cone and flowing quietly down the slope. It was not much larger than the stream of liquid iron which flows from an iron-furnace to the moulds which await it, but in the motion all the essential features of the greatest of these fiery torrents could be seen. The surface of the fluid, cooled in the air, slowly hardened into a viscid scum. This scum, urged forward by the swifter movement of the more fluid matter below, was wrinkled as is the cream on a pan of milk when it is slowly poured over the edge of the vessel.

A tiny eruption such as this can be transformed into those of the greatest energy by simply increasing the volume of the discharging gases. We have only to conceive the ascending column of intensely heated steam, in place of breaking out in the separate cannon-like explosions, pouring forth in a continuous rush and mounting to the height of several miles above the vent; the increased force of the outbreak blowing away the summit of the cone, enlarging the crater until it was perhaps a mile in diameter; the steam imprisoned in the fragments of lava tossed up by the explosion expanding with great energy, not only rupturing the blocks, but rending them into powder, and the rivulet of lava magnified to a torrent such as so often sweeps down the flanks of the mountain. Thus, by a change in the magnitude of the action alone, we pass from the most trifling to the greatest eruptions.

This glance at the history and structure of Vesuvius serves to give us a general notion of eruptions; we see that they are essentially jets of extremely heated steam, and that the ashes and lava, though they are the only permanent remains of the successive explosions, are by far the least important

element of the matter cast forth during an eruption. It seems probable that if we could gather again all the water which in the form of steam has poured from Vesuvius since the cone began to form, we should find that it amounted in mass to several times as much as all the ash and lava which

Vesuvius looking East from the Observatory 1880 showing Vent cone and Old Eroded Pedestal of Lava and Ash

The dark line on the right of the cone is the railway up the mountain

forms the cone. This water falls in torrential rains in the region about the crater, or drifts away in clouds to other countries, and so leaves no sign except in the furrowed sides of the volcano, which are deeply eroded by the floods that attend the greater eruptions. We may compare the explosion of a volcano to the action of a bursting boiler, when in a moment the rupturing agent disappears in the air, leaving

only the fragments of the vessel which contained it and which it has torn to pieces.

A large part of the materials thrown out by a volcano does not fall upon the cone; in most of the eruptions of Vesuvius the dust has been the largest part of the solid matter cast forth, the lava perhaps not amounting, on the average, to as much as one-fiftieth of the mass of rock-material ejected. The coarser part of this dust falls in the region near the cone, but a large share of it drifts to great distances, to darken the skies, it may be, a thousand miles away. During several of the great eruptions of Vesuvius the dust which fell within ten miles of the crater formed a stratum averaging more than a foot in depth, greatly exceeding in volume the ejected lava; still it seems likely that by far the larger part of this dust did not fall near the crater, but was borne by the winds far and wide over land and sea.

We may here remark the fact that the quantity of dust ejected during a volcanic explosion varies very greatly, not only in different volcanoes, but in various eruptions from the same cone. The quantity of this comminuted material as well as its fineness of division appears to depend upon the energy of the explosion. Where the movement of the materials upward through the throat of the volcano is relatively slow, the steam produced by the water originally imprisoned in the confined interspaces of stone boils out of the lava and escapes in clouds of vapor. Where the uprush of the lava is swift, each little vesicle of water swiftly expands and blows the rock into extremely fine bits. The nature of the action can be made more readily understood by a reference to an interesting mechanical contrivance which was invented to make paper pulp from the stems of the common cane. In this contriv-

ance the hard woody matter of the reeds was enclosed in a strong iron cylinder shaped much like an ordinary cannon.

Showing Volcanic Tufa of Naples in which Subterranean Dwellings have been Excavated

Deposit formed of volcanic ash laid down on the sea-floor during prehistoric eruptions in the Vesuvian district

The vessel had a lid which closed the mouth of the chamber. Into the hollow of the gun the cane was charged, along with

enough water to enclose the mass of stems. The entrance to the chamber being closed by the lid, the gun was then heated to a temperature far above the boiling point of water. Restrained by the pressure, the water did not pass into steam, but the fluid within the interspaces of the woody matter was brought to a temperature at which it would immediately pass into the state of vapor as soon as the pressure was removed. After some hours of heating, the lid of the gun was suddenly opened, whereupon all the water passed into the state of steam, the cane was blown into bits, and the mass driven forth from the gun. This process, whereby the woody fibre was finely divided through the expansion of the contained steam, is exactly the same as that by which the imprisoned water in the lava disrupts the stone when the mass escapes from the pressure of the earth into the open air.

After the reader has conceived the magnitude and continuity of the Vesuvian eruptions, it is well to consider that this vent is really a very small affair, not deserving to rank as more than a third-rate volcano, if we determine the order of importance by the size of the cone, the diameter of the volcanic tube, or the velocity of the eruptions. The family of Italian volcanoes includes at least three other vents which have, or have had in their period of activity, a larger measure of dignity than the Vesuvian cone. Ætna has at least twenty times the bulk, and presents to us phenomena of Vesuvius exhibited on a far greater scale. Among the numerous dormant or extinct volcanoes which lie along the shore between Naples and Southern Tuscany, those of Bracciano and Bolsena, whose vast craters are now occupied by lakes, were in their time far more majestic than Vesuvius. The crater of Bolsena now affords a basin for a lake having an area of about

forty square miles, and yet the whole of its vast expanse is not completely occupied by the sheet of water. It is doubtful if the area of the Vesuvian crater was ever six square miles. That of Bracciano is smaller than Bolsena, but still several

Crater Lakes of the Sevon Cities St Michael's Azores

There are two of the craters united by the breaking down of a part of the bordering walls

times as large as the Vesuvian crater. These two volcanoes of Bolsena and Bracciano were giants in their youth, but they came to an untimely end. Their subterranean fires were extinguished before they had time to construct cones at all proportionate to their vast orifices.

Although the total number of volcanoes, active and extinct, amounts, in Europe, to several hundred, including those of Central France and Germany and the peripheral cones of Ætna, we must go beyond the bounds of that continent to find instances of eruptions of the first order. The noblest and most characteristic volcanoes, whether we class them by the energy of their explosions or the volume of their ejections, are found in Iceland and in the Malayan Archipelago. In Iceland the volcano of Skaptar, in the single eruption of 1783, poured out a tide of lava exceeding in bulk all that has flowed from Vesuvius and Ætna combined since the eruption of Pliny. It has indeed been computed to be greater than the mass of Mont Blanc. The gas-eruption which attended this molten tide was proportionally great; the clouds of fine cinders floated over Europe and so darkened the sky as to occasion fears of some great calamity. Although Iceland is a thinly peopled country, this catastrophe was extremely destructive to human life; nearly a fifth of the population perished in the villages which were overwhelmed by the eruption, from the famine which came from the loss of the year's crops, and the frightening of the fish from the neighboring sea.

The whole of the island of Iceland is composed of volcanic matter, which has been cast forth in a succession of eruptions within modern geological periods. There have probably been scores if not hundreds of eruptions in Iceland as great as that of 1783. Again and again we must conceive these explosions to have poured their dust and vapor into the atmosphere, scattering the stony waste far and wide over the bottom of the North Atlantic and the lands which border it. The eruption of 1783 was the greatest in the history of this volcanic

district, but such explosions have probably been frequent in the development of the island.

It is interesting to note the effect of this eruption on the minds of the people in the eighteenth century and to contrast it with that arising from the great eruption of Krakatoa hereafter to be described. The outbreak of Skaptar in 1783, as well as that of Krakatoa in 1883, cast a great deal of watery vapor and of finely divided ash into the atmosphere. In both cases the skies were much clouded by the emanations, which produced a singular redness at dawn and eve. A century ago this change in the aspect of the heavens produced a profound and wide-spread fear, a sense of impending calamity; even the poet Cowper, a well-informed gentleman of his time, held this phenomenon to indicate in some way the wrath of God or to be a presage of ills to come. Science had no place in the public discussion of these facts in the eighteenth century; on the other hand, in 1883 the much more wide-spread and conspicuous disturbance of the air due to the eruption of Krakatoa became at once the matter of scientific inquiry. The public mind was in no way made anxious about the singular condition of the heavens; science came in to explain the phenomenon, and the reasoning was immediately grasped by the public. In this contrast we see clearly the effects of advancing natural learning and the consequent change in the attitude of men toward natural phenomena.

The thousand years of struggle which the Icelanders have had with polar cold and central fire is one of the most pathetic incidents in the history of our race. Almost every generation on that island has borne a heavy burden from earthquake-shocks or volcanic explosions, and yet this people have managed, by labor and thrift, to develop and maintain a well-

ordered civilization. For centuries the social order has been more secure, education more general, and the moral quality purer than in the happier parts of the world. Everywhere else save in this marvellous island we find that the effect of a hopeless contest with physical ills is to degrade man in spirit. Owing to the rapid extension of the Darwinian hypothesis, we find many historians disposed to explain the intellectual and moral conditions of people by means of their physical surroundings. There are those who are disposed to account for the culture of Greece, in part at least, through the influence of its benign climate, and to explain the retardation of tropical peoples or those near the poles by the burden which nature imposes upon men in such situations. The intellectual history of Iceland when properly considered must give us pause in such speculations, for it shows us that the innate qualities of the people may go far to exempt them from the influence of their surroundings. It is true that Iceland has developed no art, but in every other feature of its intellectual development there is much analogy between the folk of this afflicted land and those of the fortunate region of Hellas: an intense political life, a strong historic spirit, and poetic motive, less wide-ranging but fit to be compared in intensity with that of Greece, mark their intellectual development. There can be no doubt that men are greatly influenced by their physical surroundings, but the fact that there is a limitation in the measure of this influence is clearly shown by Icelandic history.

Although Iceland's Skaptar is a great volcano, and as a lava-producer has perhaps the first place among volcanoes, it is in the region about the Pacific Ocean that we find the kings of this race of giants. Around the shores of this great area of

waters we have a singularly continuous line of volcanic vents. Counting only those which have been in activity since the beginning of the present geological period, the aggregate probably amounts to many hundreds. Although the volcanic energies are, or have recently been, violent in all parts of this vast field, they exhibit their maximum energy in the central

Volcanic Cone, Sandwich Islands, showing the Aspect of Crater walls and Floor after the Surface has been Covered by Vegetation

part of the great Malayan Archipelago. This region has been well termed a "rookery of volcanoes." Not only are great cones more numerous in this field than in any other equal area, but we have had there the greatest eruptions of which we have any historical record. We can note only a few of these great explosions.

In 1772 Papandayang, a great volcano over nine thousand

feet high, broke out with such violence that the upper part of the cone for a height of four thousand feet was tossed into the air, and, together with a prodigious amount of ashes discharged by the eruption, overwhelmed forty villages. In 1822 Sumbowa, on an island a little to the east of Java, was the seat of a yet more powerful eruption. As in the other great explosions of this region, the sound was heard a surprising distance, being audible in Sumatra, nine hundred and seventy geographical miles to the west, and at Ternate, seven hundred and twenty miles to the east. This is as if a volcano at Chicago should make its explosions heard by the people in Boston and Omaha. The fall of ash and pumice was enormous; it crushed buildings more than forty miles from the crater. Whirlwinds, caused by the atmospheric disturbance common in all great eruptions, rent the forests from their roots, and did much to complete the catastrophe which reduced a populous and fertile region to a desert. Of twelve thousand people in the province of Tomboro, in which the crater is situated, but twenty-six escaped alive. In 1822 also Galongoon, a crater never before known to have been in activity, exploded with extreme violence, and in a period of four hours covered the country about it with a thick coating of ashes and hot mud, destroying one hundred and forty villages, with a loss of four thousand lives. This coating of mud was so thick that for the distance of twenty-four miles on one side of the mountain there were no visible remains of the numerous settlements which had existed there before the eruption began.

In 1883 a century of gigantic eruptions was completed by the outbreak of Krakatoa, by far the greatest explosion of which we have any account. Krakatoa is a small island lying between the greater masses of Java on the east and Sumatra

on the west. Although manifestly a volcano, it is likely that it had never within historic times been in eruption until May 23, 1883. At that time it was the seat of an outbreak which was considered trifling, only adding one more to the many points of modern volcanic activity in that region. The eruption was soon over, and on the 27th of the month many observers visited the mountain to note the changes which it had brought about. For three months it seemed absolutely quiet; but in August of the same year, with little preliminary commotion, a memorable outbreak occurred. Nearly the whole of the original island was blown away down to below the sea-level, probably at the first discharges of the gases, so that the greater part of the eruption took place from the floor of the sea. The violent boundings of this floor created vast waves in the ocean, which rose to the height of fifty or sixty feet along the populous shores of the neighboring islands of Sumatra and Java, sweeping away villages and plantations, and killing over thirty thousand people. Thence, with diminishing height, these waves rolled onward like the tides until they were felt in the Northern Atlantic and along nearly the whole of the Pacific shore.

The movements which this shock impressed on the atmosphere were even more remarkable than those which it gave to the sea. The sounds of the explosions were heard for double the distance to which we have any record of their having been audible in previous eruptions. If an eruption of Skaptar in Iceland should be audible at once along our great lakes and upon the Mediterranean, we should have a case of sound-transmission comparable to that in Krakatoa in August, 1883. The waves of the air caused by the sudden pressure of the escaping gases rolled around the earth, twice girdling its cir-

cumference. Besides the enormous mass of dust which fell upon land and sea within a few hundred miles of the point of explosion, which probably amounted in bulk to as much as twelve cubic miles, an unknown amount of the more finely comminuted rock remained for a long time suspended in the

A Crater in the Sandwich Islands at the Close of Eruption, Showing Lava-terraces and Stratified Nature of Cone

atmosphere and was floated over all parts of the earth's surface, giving to the sky at morning and evening the memorable ruddy glow it presented in the two years following the eruption. The amount of this widely scattered matter cannot be accurately computed, but it possibly exceeded in volume that which fell about the crater.

The foregoing brief review of volcanic eruptions will, in a limited way, suffice to show the reader the immediate physical importance of these accidents, and the extent to which they may enter into the conditions of human life. They will not, however, give him any measure of the range and constancy of this volcanic action, or the part it plays in the machinery of the earth's crust. To gain some notion of this he must imagine many thousands of these vents scattered over the sea-floor or along the shores of the continents, all of which have been active in recent geological times. He must, furthermore, conceive that at every stage in the earth's history there have been similar, perhaps equally numerous, volcanoes at work. It is doubtful if since the beginning of the geological record there has been a day during which some crater, great or small, has not been hurling its gases toward the sky, scattering its dust over the fields of land and sea, and destroying with its attendant earthquakes, or by its emanations, the life of air or water. Lying as they do along the shores or in the fertile islands of the ocean, these vast engines of destruction are a perpetual menace to many of the most fruitful and beautiful parts of the earth; they therefore have an element of human as well as scientific interest, leading us to investigate the nature of their cause and their relation to the mechanism of this planet.

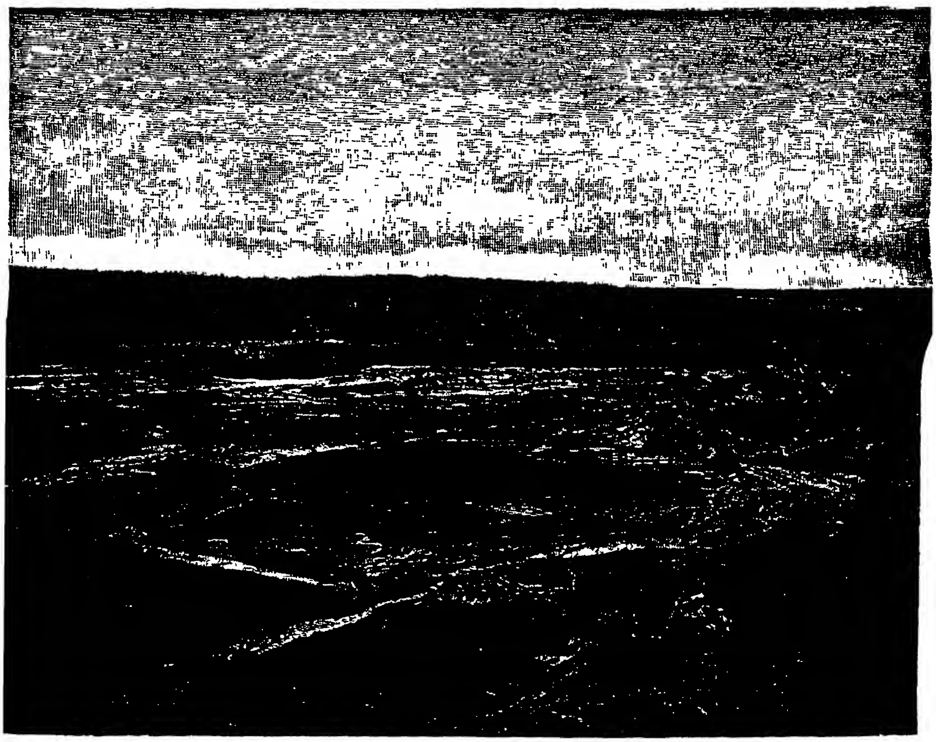
In seeking to explain any of the superficial phenomena of our globe, it is well to begin the inquiry by considering the manner in which they are distributed over the surface. When we have clearly delineated on a map the distribution of any important phenomena over the surface of the earth,—when this distribution is effected not only for the present period, but for different ages in the past,—the features which we seek to

explain are assembled in such a manner that the mind readily takes hold upon them. We are then almost sure to be led by the order of the facts to a rational explanation of their origin. All the more important discoveries of geology have evidently been made, however clumsily, by this method of inquiry. It is therefore well to accept it as a principle and to adopt the method in all fields of research where it can be applied. In this way we are most likely to come upon a clew to the origin of any unexplained feature of the facts.

A glance at the geographical position of volcanoes suffices to show us that they are very peculiarly grouped in and about the great water-areas. Probably all of the active vents in the earth's surface lie on the floor of the oceans or greater seas, or within a few score miles of their shores. We may, indeed, say that active volcanoes normally occupy the floor of the seas as their proper field, and that this volcanic area here and there overlaps the shore for a very small distance. Moreover, among the extinct volcanoes which lie far inland, we can often observe that their activities ceased soon after the elevation of the continent forced the sea-margin far from their bases. It was long ago perceived that these facts indicated a necessary connection between the effects brought about by large masses of water and the volcanic explosions. At first it was suggested that the sea-water penetrated through crevices to the heated interior of the earth, and there, being converted into steam, was expelled through the volcanic vent along with the lava from a central molten mass. But it was directly seen that the facts were against this hypothesis; for why should the volcanic emanations not return to the surface by the same crevice which gave the water access to the earth's interior? Why should the lava of Ætna and

other volcanoes rise against its own enormous pressure to the height of twelve or fifteen thousand feet above the tube by which the sea-water penetrated to its base?

It has since been suggested that the water from the seas gains access to the central heat while it is imprisoned in the fine interstices which lie between the grains of the rocks,



Lake of Lava in the Sandwich Islands, showing Deposit of very Fluid Lava.

passages which are too small to permit the exit of the gases. A curious experiment at first appeared to make this notion plausible. As was shown by the distinguished naturalist Daubrée, if we take a vessel of metal and fix upon its top a sheet of dense sandstone, so that the chamber is air-tight, then place water upon the top of the sandstone, and finally apply heat to the base of the metal chamber, the water will

penetrate through the interstices of the stone and generate steam in the enclosed space, producing a pressure which is much greater than the gravitation-force which impels the water to descend through the stone. If we provide an avenue of escape for this steam by means of a pipe filled with mercury, we shall find that it will force the mercury up the tube, much as the volcanic steam pushes up the lava in the crater. It is evident that we have here what seems, at first sight, like a promising explanation of volcanic action: we have only to conceive that water penetrates through the interstices of the rock on the sea-floor, just as it does through the slab of sandstone in the experiment; that the internal heat is represented by the lamp, and the volcanic tubes with their contained lava by the pipe containing mercury, to have the likeness complete. But a little consideration shows that this explanation will not serve us at all. It is true that the rocks beneath the sea-floor contain a good deal of water—all, in fact, that their interstitial spaces will hold—but this is equally true of the rocks beneath all parts of the continents. The rain-water of any country, however slight in amount, is sufficient to fill the crevices of the rocks to repletion, if, indeed, they were not so filled when they were formed on the sea-floors. We know this from mines in the land, as well as by many galleries which penetrate below the sea-level from shafts near the shore. We are, therefore, driven to another hypothesis, which is entirely satisfactory. It was long ago suggested, though it has not been presented in a perfectly clear form in our popular treatises on the subject. This explanation may be stated in a few words:

When deposits of rocky matter are laid down upon the sea-floor, they contain a good deal of water. Such deposits

are never entirely compact; there are numerous little spaces between the grains of sand or mud, in or between the fossil shells and other animal remains, which form in most places a part of the strata as they are made. We see how large an element water is in such beds if we take up a portion of the mud from the bottom of any pool. It is probable that, on the average, this enclosed water amounts, at the time when the deposits are made, to as much as from five to fifteen per cent. of the mass. At first this imprisoned water is at the ordinary temperature of the sea-floor, and so has no tendency to break out of its cells; but in the course of the geologic ages, a great many thousand feet of strata are slowly accumulated above the original level, all charged in the same way with a portion of the fluid in which they were laid down. We have now only to see a means whereby this rock-encased water can be raised to a high temperature—say to the heat of two or three thousand degrees, Fahrenheit—in order to bring it to the state of the steam which, escaping from rents of the earth, gives rise to the explosions of volcanoes

This means of heating is provided by the continuance of the very process which builds the water into rocks, viz., by the deposition of strata and in the following manner: Heat is constantly escaping from the earth's interior, which, though probably solid, is extremely hot; the temperature of the central portion is very likely to be measured by tens of thousands of degrees. Whenever we penetrate by wells or mines into the earth, we find a constant increase of temperature as we descend. It is likely that beneath the sea-floor this rate of increase is somewhere near one degree to every fifty feet of depth, varying with the ease with which the heat finds its way out through the different kinds of rocks it encounters. Any-

thing like this rate of increase would give us a temperature of several hundred thousand degrees at the earth's centre.

It may well be the case that the internal heat does not increase with the same rapidity as we descend toward the central regions, but for a score or two of miles this increase most likely continues at something like this proportion. It is thus easily seen that the heat of any mass of buried rock depends on the thickness of the matter deposited above the level, for it is that blanket of strata holding in the heat which causes its temperature to be above that of the earth's surface. In the case of a deposit made on the sea-floor and covered by a blanket of strata ten thousand feet thick, the outflowing tide of heat will be restrained in its escape, and the temperature of the buried matter will in time rise to about two hundred degrees above the temperature which it had at first, or to near the heat of boiling water. Another ten thousand feet of strata may raise the temperature high enough to produce some of the slightest volcanic explosions—those in which the rocks are not melted, but simply blown away—while with a deposit one hundred thousand feet thick, the rocks might in time hold in enough of the outflowing heat to produce the most intense volcanic activity, where the expanding gases act with more than the violence of gunpowder.

If the reader has any difficulty in conceiving the effects of overlaid beds in bringing about a high temperature in strata, he may help himself by a homely comparison. Let him imagine a vessel containing hot water exposed to the cold and covered with felt or other non-conducting material; the surface of this covering will have a certain temperature. If now this vessel be covered with another thickness of felt, the temperature of the original surface will rise, and a certain gain

of its heat will be made by each additional coating of non-conductive material.

The only serious question is as to the thickness of the rocks which have been laid down on the sea-floors. Hardly any geologist will doubt that it is entirely within bounds to

Border of Lava-stream in the Sandwich Islands showing the Form Assumed by Partly Cooled Lava Note the "Roping" in the Lava

assume that thickness much to exceed twenty miles. It may well have attained to twice or thrice that depth since the geologic ages began, for in our continents we see that the aggregate thickness of the successive beds exposed to view, despite the great erosion to which the lands have been exposed, amounts to somewhere near one hundred thousand feet of strata. It must not be imagined that the deposits on the

floors of the sea were ever laid down in water having the depth of ten miles or more. The truth is, that the sea-floors have been gradually sinking as the lands have grown upward. The lands have furnished, from their shores and from the rivers, sediments which have gone to make the strata which the sea has deposited, and the ocean-floors have slowly bent downward as they received these accumulations of waste. As we shall shortly note, a very important part of the materials contributed to the sea-bottoms comes from the volcanic ejections themselves. We thus see that in the water imprisoned in the deposits of the early geologic ages and brought to a high temperature by the blanketing action of the more recently deposited beds, we have a sufficient cause for the great generation of steam at high temperatures, and this is the sole *essential* phenomenon of volcanic eruptions. We see also by this hypothesis why volcanoes do not occur at points remote from the sea, and why they cease to be active soon after the sea leaves their neighborhood. While deposition of strata is going on with moderate rapidity, as it generally is over the sea-floors, the heat is constantly rising in strata and the tendency of the imprisoned water to pass into steam continually increasing. On the land areas, however, the rocks are constantly becoming cooler, and the expansive energy of the steam which causes the eruptions becomes proportionately less.

Conceiving, then, the rocks at a depth of ten or twenty miles below the surface of the earth to be filled with steam at a temperature near two thousand degrees, Fahrenheit, we may readily explain a part of the phenomena of volcanic action, viz., the formation of the gases essential to their explosions. It remains for us, however, to account for certain facts con-

cerning the movement of these gases toward the chance openings by which they find their way to the surface of the earth. It may well be asked, Why do these imprisoned vapors not make their way directly upward through the rocks, passing through the interstices which contain the water? The reason for this doubtless is, that as the cooler rocks above are very close-knit, they offer much the same obstacle to the migrations of the steam as is afforded by the iron walls of a boiler. The only way in which the imprisoned gas can escape is by a lateral motion in the level of heated and softened rocks toward any point where a break offers them passage to the surface. Such breaks, extending very deeply down into the rocks, are extremely common.

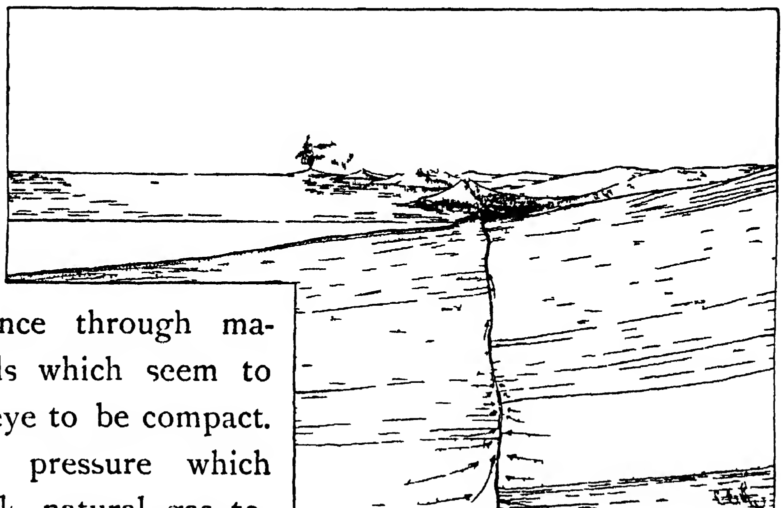
Let us imagine such a break or fault to be formed, leading down to the depths of imprisoned water where the rocks have a temperature of more than two thousand degrees, Fahrenheit. At once the water near the opening will make haste to avail itself of the chance of escape. As it is contained in every part of the imprisoning rock which is softened by heat, the water in passing to the point of escape will drive the rock before it, much as the baker's dough is moved by the imprisoned gases of fermentation. As it comes to the surface the steam may, to a great extent, escape in advance of the liquid rock, blowing some portion of it to bits as it rushes into the air; or the whole of the softened rock may be blown into dust, as in the greater eruptions we have before noted. This discharge will terminate when the energy of the outrush of the steam is so far diminished that the column of lava in the volcanic pipes can by its pressure retain the vapor. Then there will be a pause of some duration.

A familiar instance of the process by which a mass of lava

is converted into pumice may be found in the slag of our iron-furnaces. This slag, as is well known, is molten rock, and in its general character resembles the lava poured forth from volcanic vents. Like the lava of the volcano, the slag of the blast furnace is under a considerable pressure when it escapes from the vent. In the furnace there may be fifty or sixty feet of ore and fuel above the level whence the molten iron and slag are drawn. In the volcano there may be a thousand times or more of rock material above the lava when it starts upward through the throat of the volcano. When the slag discharges, the imprisoned vapors, hitherto strongly compressed, are free to expand, and in many cases they blow up the molten rock which contained the metal into a spongy mass, producing a pumice which is often difficult to distinguish from that formed by volcanoes.

After a time the steam from regions horizontally remote from the point of escape will creep in toward the vent, accumulate pressure there, and so gradually again reproduce the conditions of another explosion. As this imprisoned steam works toward the point of escape, it may drive before it the rock in which it is contained, and so furnish a continued supply of melted material for the discharge of ashes and lava; or it may pass through the interstices of the beds without forcing the softened rock to accompany it. We have many evidences of such a horizontal movement of gases alone, or of rock and gases combined, from our experience in mines and other subterranean explorations. When in a deep coal mine we have horizontal galleries cut in beds of clay, with hard rocks above, we often find that the clay creeps upward from the bottom and inward from the sides until it fills the cavity. When cut out it continues the movement, putting the miners to much trouble

in order to keep the way open. This shows us how, under the inconsiderable pressure of a relatively slight weight of overlying beds, rocks which seem tolerably hard may creep toward a point of relief. Then, again, in the movement of gases contained in rocks, we have evidence that, even when urged by pressures which are slight compared with those of the volcano, vaporous matter can travel for a considerable



Hypothetical Section through Rocks near a Fault on which a Line of Volcanoes has Formed

The arrows show the direction of the movement of gases, their length the relative energy of the movement

distance through materials which seem to the eye to be compact. The pressure which impels natural gas toward the bored well through which it discharges is most likely not greater than a thousand pounds to the square inch. This is possibly not the hundredth part of that which impels the gases in great volcanic explosions; yet as a well will sometimes discharge ten to twenty million feet of gas per diem for years, it is evident that this store of gas must be derived from a very wide field. It is probable that in some cases it may journey for miles toward the outlet. If the rocks were hot it would be possible for the imprisoned gas to make channels of escape by blowing the rock before it. We can, therefore, well im-

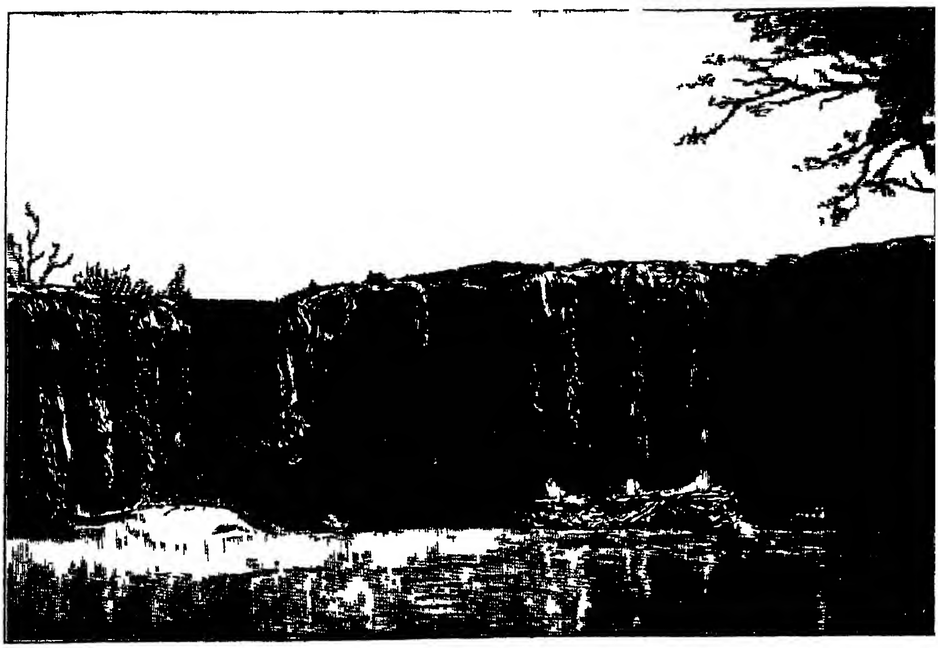
agine, in the case of the volcanic vapors, that owing to their far greater pressure and to the softer condition of the rocks they traverse, they may migrate for hundreds of miles to the point of escape.

It seems necessary to suppose that our volcanoes are fed by the gases and lava from a wide field, for the reason that, notwithstanding the enormous amount of materials they throw out, the ground about their bases rarely if ever seems to be lowered. For instance, in the case of Vesuvius, the water in the form of steam, the lava and ashes which have emanated from it, since the Christian era, have amounted probably in all to more than five cubic miles, yet there is no evidence that the cone or the country about it has permanently subsided in that time. It seems, indeed, here and there, to sway up and down from age to age, but the average height above the sea remains essentially unchanged. Unless the supply of the ejected materials comes from a very wide subterranean field, the surface of the region should show a decided subsidence.

The evidence of this sort which has been obtained from the study of Ætna is even more conclusive than that which we observe in the case of Vesuvius. Ætna has poured out a volume of discharged matter many times as great as that which has escaped from Vesuvius. It seems, from data which cannot be considered here, that since the beginning of its history Ætna has discharged a volume of vapor, ash, and lava which, when buried in the earth below, must have occupied at least one thousand cubic miles of space, and yet so far from the foundations of the mountain having sunk down, the base of the cone has been considerably elevated during this time when material was coming forth to the earth's surface. The only way in which we can account for this failure of the

ground about the mountain to subside is by the supposition that the ejected materials in the main are derived from regions remote from the foundations of the cone.

The foregoing considerations make it tolerably clear that volcanoes are fed from deposits of water contained in ancient rocks which have become greatly heated through the blanketing effect of the strata which have been laid down upon them.



A Front of a Lava stream Fall ng n R vulets Into the Sea Sai dw ch Islands

The gas which is the only invariable element of volcanic eruptions, is steam ; moreover, it is the steam of sea-water, as is proved by analysis of the ejections. It breaks its way to the surface only in those parts of the earth which are near to where the deposition of strata is lifting the temperature of water contained in rocks by preventing, in part, the escape of the earth's heat.

In the extended discussions which have taken place among

geologists concerning the origin of volcanoes, much reference has been made to the singular pits, apparently of volcanic origin, which are extensively scattered over the surface of the moon. In fact, the side of our satellite which is turned toward us, and probably the portion which is turned away as well, is pitted all over with cavities which, in a general way at least, seem like terrestrial volcanoes. In all cases there is about the crater-like cavities of the moon walls which resemble the cones of ordinary volcanoes. Although there is a general likeness between lunar volcanoes and those of the earth, the differences are very evident. In the first place the lunar craters are, unlike the terrestrial, distributed all over the surface of the sphere; they are not arranged with distinct order. In size they vary from three hundred miles or more in diameter to patches which are not more than a few hundred feet across. In all cases the crater or cup is very wide and deep as compared with the surrounding wall of the cone.

These peculiarities of structure and of distribution make it at once apparent that we cannot assume an exact likeness between the lunar and terrestrial volcanoes. The problem is one of much difficulty and cannot adequately be discussed within the limits of this chapter. It seems, however, most probable that the lunar volcanoes were formed when the mass of our satellite cooled from its original state of igneous fluidity. The pits were probably produced by the boiling action during which the gases imprisoned in the sphere escaped from the surface. For some reason these gases have not remained as an atmosphere about the moon. It is a reasonable conjecture that they have been absorbed in the crevices of the very porous crust. Owing to the lack of any permanent atmosphere, the moon has never had any water upon its sur-

face, at least no part of that surface now exhibits the effect of water action. It is probable that the earth was at one time pitted over with volcanoes substantially like those on the moon, which were due to the boiling which took place as the planet cooled; but after the formation of these aboriginal craters, water began its work on the earth's surface, and in time it entirely effaced the original volcanoes, and in the manner above described created another class of these vents.

A careful study of the broad low cone of Mt. Ætna supplies us with an excellent illustration which serves to show the general method in which volcanoes of the type of those now existing on the earth are formed. On the flanks of Ætna, somewhat remote from the cone of eruption, but in the wide disc over which the lava is poured and the ashes showered in great abundance, there are hundreds of small cones, from a few score to a few hundred feet in height, which are the results in most cases of single gas eruptions of short duration. The history of these little craters seems to be as follows: The loose-textured materials of the cone contain a good deal of water. When the lava-streams freeze over, the fluid lava below the surface flows out and leaves caves in the manner described in the chapter on the formation of caverns. In time these subterranean recesses become filled with water, which percolates from the surface. When, now, the heat from the underlying lava penetrates to these masses of buried water, there to turn into steam, an opening is broken through the overlying material and a brief eruption ensues. Similar outbreaks of a yet more easily comprehensible character have been observed during the eruptions of Vesuvius. As has been before noted, many of these eruptions have invaded the village sites on the flanks of the mountain. The people of this

district secure water for their domestic purposes by means of cisterns, the porous volcanic deposits affording no wells or running streams. When the current of lava passes over one of these cisterns, the stone coping of the reservoir commonly prevents the ingress of the semi-fluid lava into the cavity until a considerable thickness of material has gathered above it. When finally the lava comes in contact with the water, a quantity of steam is produced, which for a time blows up a cone of eruption about the point where the vapor escapes. When the supply of water is exhausted, the flow of lava destroys the little cone.

From these theoretical considerations as to the causes of volcanoes it will, perhaps, be a relief to the reader to turn to the question of their place in the economy of the earth. Although volcanoes are agents of great destructive violence, we easily see that they render an immeasurable service to the earth by returning to its surface a great store of materials which are necessary to the functions of life and which are constantly being buried in the deeper parts of the crust, and so withdrawn from the activities characteristic of the superficial part of the globe. Let us consider, in the first place, the action of volcanoes in returning buried water to the seas. We have noted the fact that when strata are deposited on the sea-floor they contain a large amount of water; it is probably safe to assume that on the average not far from ten per cent. of the mass consists of this material. As the average depth of the oceans is not far from fifteen thousand feet, it is evident that the amount of water thus abstracted by the deposition of strata from the earth's surface, in the course of the geologic ages since the ocean came upon the surface of the earth, has

been very great. If the thickness of the part of the crust which has been laid down on sea-floors amounts to as much as one hundred and fifty thousand feet, the oceans might have disappeared in their own deposits, and so the surface of the earth would have had a limit put to its most important processes. But by the operations of the volcano a large part

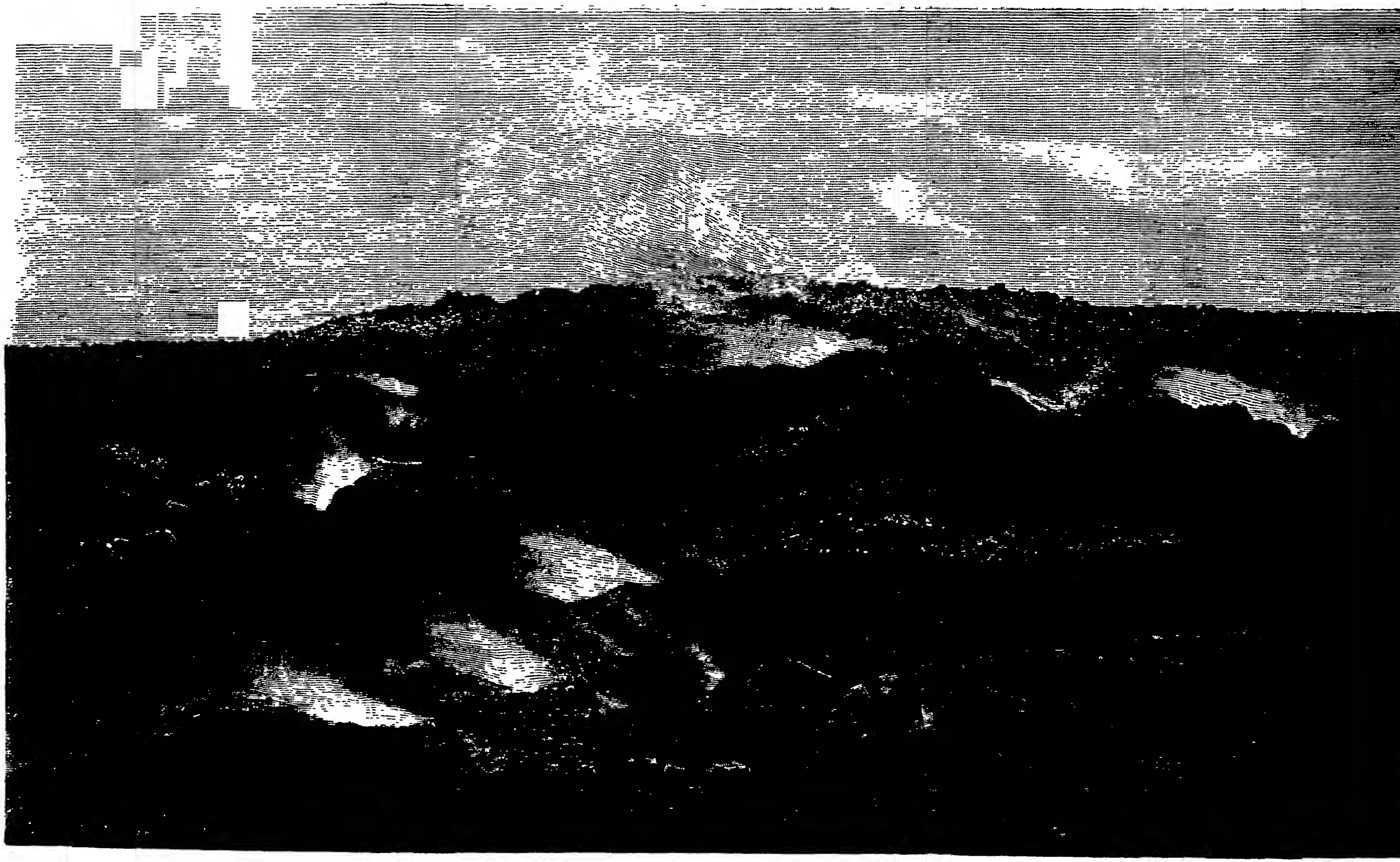
B The Same Lava stream Pouring in Full Tide into the Sea

of the imprisoned water is in time restored to the earth's surface, and so reënters on its beneficent activities.

With the steam from a volcano there comes forth also a considerable amount of the carbonic-acid gas which must be present in the air, else vegetation would cease to be. A very great amount of this substance is each year taken from the atmosphere and buried in the earth, not only by the plants and animals, the carbon of whose remains are buried in strata

but also by certain processes of decay of rocks, as where the felspar of granitic materials is converted into kaolin. About the only manner in which this carbon can find its way back into the air is through volcanic action. It is not likely that volcanic activity can restore enough of this carbon in the form of carbonic-acid gas to compensate for the constant and rapid burial of the substance in the earth, but it is certainly a means whereby a good deal of it is returned to the atmosphere. In certain cases the emanation of this combined oxygen and carbon from volcanoes is in such volume that it is extremely destructive to life; being a heavy gas, it flows like water down the sides of the cone, carrying with it death to all animals. Such destructive effects are limited to the first and last stages of an eruption. When a volcano is reduced to its last stages of activity, when it is only a smouldering vent, it often continues to pour forth this gas long after it has ceased to produce any other evidence of its connection with subterranean processes. A good case of this is seen in the Solfatara, near Naples, where a small crater, long since extinct as a volcano, throws out enough carbonic acid to suffocate a dog, to the diversion of hard-hearted tourists and the profit of the proprietors of the brutal show.

The solid matter thrown out by volcanoes is the most important contribution to the materials which the sea has at its disposal for the nourishment of its life and for the formation of strata. The quantity of the pumiceous and finely pulverized material is, as we have seen, enormous. When it falls upon the sea it either floats for a time or at once sinks into the depths. In either case it is, to a great extent, dissolved in the ocean waters, and so contributes to the store of materials which may be appropriated by the organic life of

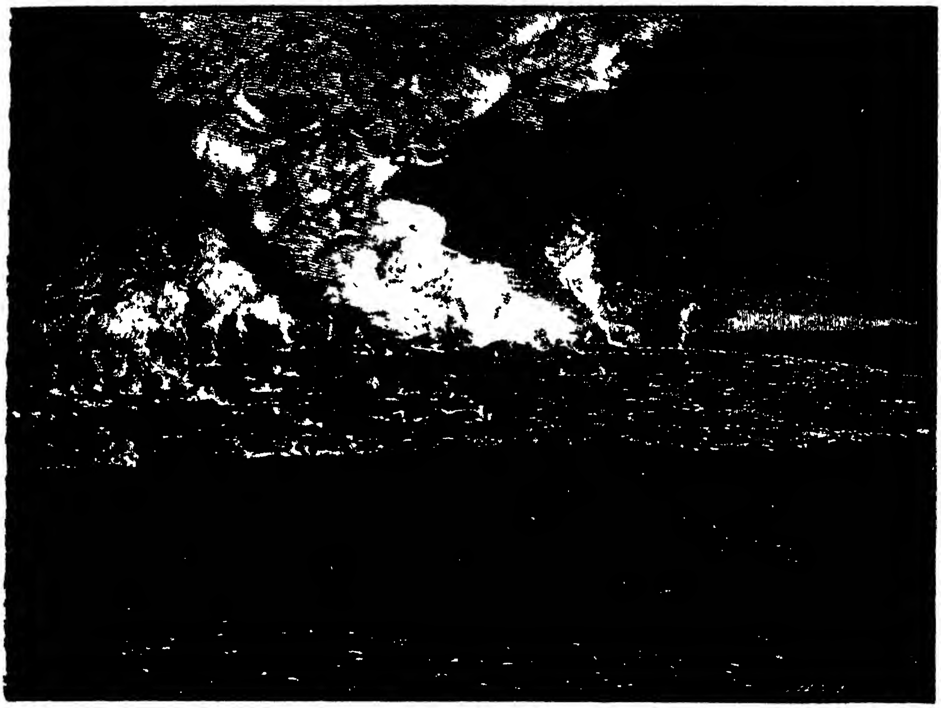


Crater in the Sandwich Islands at the End of an Eruption. The Lava still throwing off Steam.

the sea. When it falls on the land, it is generally so incoherent that it is easily swept away by the rains, and so comes quickly into the ocean. The importance of this contribution to marine sediments has been overlooked by geologists, but it is easy to see that it may amount in mass to something like as much as the earthy matter which is brought to the sea by the rivers. The volcanoes of the Java district alone have within a century thrown out a mass of this fragmentary rock amounting probably to not less than one hundred cubic miles, and perhaps to twice this quantity. Now, the Mississippi River carries out in the form of dissolved matter, mud, and sand about one cubic mile in twenty years, or five cubic miles in a century; thus these volcanoes of the Java district have brought up from the depths of the earth and contributed to the sea many times as much detritus as has been conveyed to the ocean by the greatest river of North America. Allowing for the greater porosity of the volcanic ejections, it still seems not unlikely that the mass of rocky matter from a half dozen great volcanoes of the East Indian Archipelago, in the period of a little more than a century from 1772 to 1883, far exceeded that brought into the oceans by all the rivers of North America in the same period. Although the volcanoes of this district are by far the most powerful which are known, we still cannot fairly reckon that their ejections represent anywhere near the half of the total quantity which came to the earth's surface from such vents during the above-named period of one hundred and eleven years. For during this time some scores of great craters were in eruption, including Skaptar in Iceland, Vesuvius, Ætna, various volcanoes in South America and elsewhere. It seems, therefore, not unlikely that the solid materials contributed by volcanoes

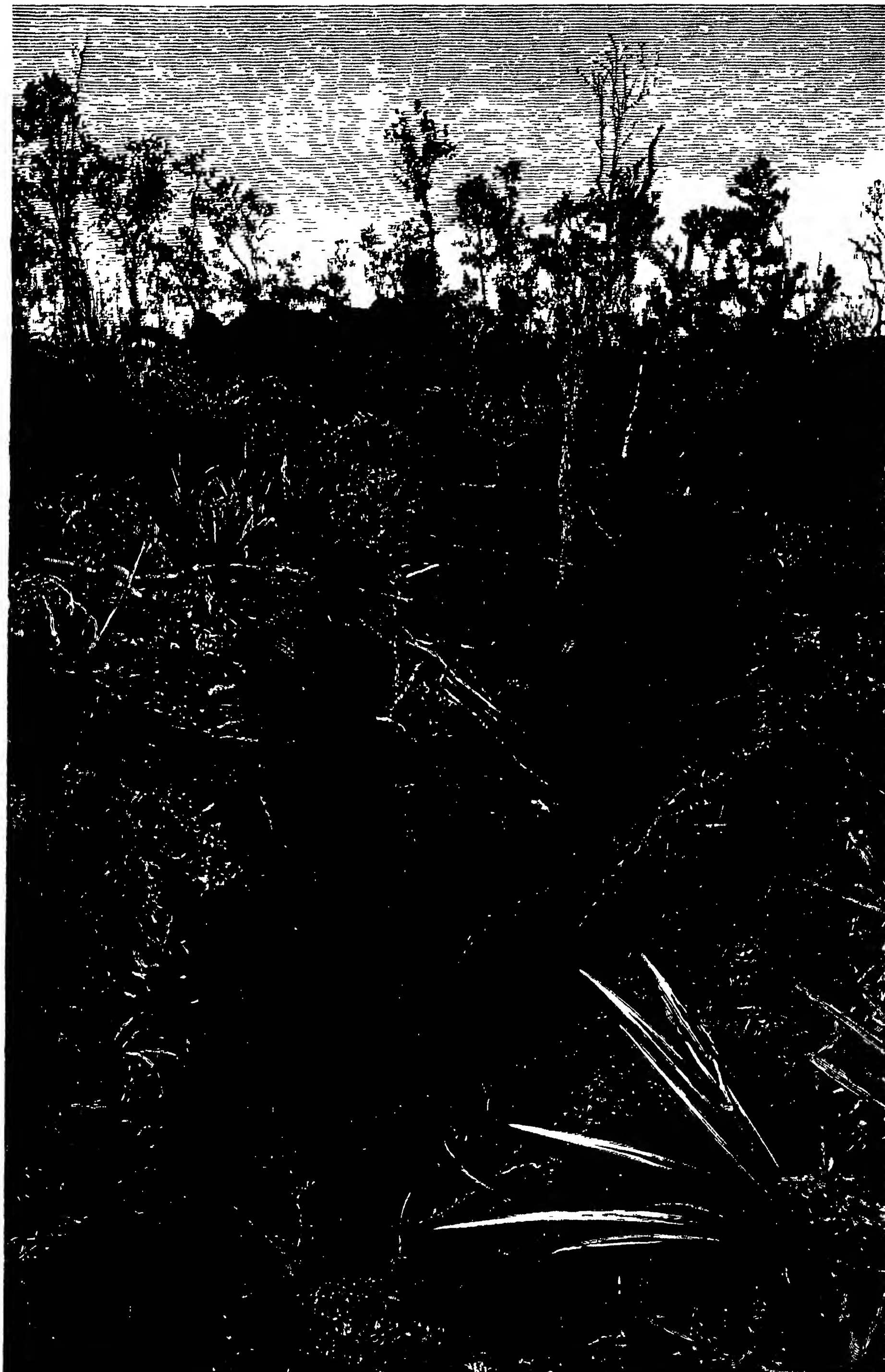
to the sea-floor may, on the average, amount to more than that taken by the rivers from the land.

A short time ago I had an excellent opportunity for perceiving the amount of the pumiceous matter which is carried about the ocean, by marine currents. On a journey up the



'ide Lava-stream at Point of Egress, showing very Fluid Condition, with Escaping Steam, Sandwich Islands

east coast of Florida, from Key West to the northern part of Indian River, I observed that the sea-shore was abundantly strewn with bits of pumice. On a close examination I found at least one bit of pumice to each one hundred feet on the length of the shore, and on examining the sand perceived that a large part of the material was composed of porous volcanic matter which had been ground by the action of the waves into small bits. It is evident that the Gulf Stream is charged with this volcanic material, and the considerable



Rent in the Earth from which Sulphurous Vapors Attendant on an Eruption have Escaped; Partly Closed by Tropical Vegetation

variety in the mineral character of the specimens appears to indicate that they have journeyed from many different parts of the earth. It is probable that all our sandy sea-shores contain bits of rock which have been floated in the form of pumice from the remoter parts of the oceans.

Among these solid substances which are ejected by volcanoes we find some of the most indispensable elements of organic life, including phosphorus, soda, potash, and other materials. The value of these materials to vegetation may be judged by the fertility which so often characterizes the regions in the immediate vicinity of volcanic cones which cast forth large amounts of ash. If the rainfall be sufficient this ash quickly decomposes into a fertile soil, which tempts the husbandman to replant the fields as fast as they are ravaged by the explosions. Were it not for the constant return of these rarer and precious materials to the superficial part of the earth by means of volcanic action, it is likely that the earth's surface would want many of the substances most necessary for organic life.

We thus see that volcanoes play a very important part in the physical history of our planet. The action is, in a large degree, restorative. They help to maintain the earth's surface in a condition in which it may nurture life. We note also that this internal heat of the earth, acting through volcanoes, serves to counteract certain injurious effects arising from the operation of the solar forces. The heat of the sun operating in the rivers and the waves wears away the materials of the land, buries them in the strata of the sea-floor along with a part of the water of the seas. The internal heat expels the most volatile and the most life-giving portions of these substances, affording them a chance to take their places once again within the activities of the surface.

CAVERNS AND CAVERN LIFE.

Effect of Caverns on Imagination.—Classification of Caverns.—Limestone Caves: Method of Formation.—Caverns of Kentucky.—Sink Holes, Shafts, Domes, and Galleries.—Formation of Stalactites.—Natural Bridges—Air of Caverns: Effects on Decay; on Health.—Relation of Primeval Man to Caverns; Dwellings; Burial-Places—Remains of Animals.—Living Animals of Caverns; Bearing of Evidence on Darwinian Theory.—Geographical Distribution of Limestone Caverns.—Hot Spring Caves; Mineral Deposits in such Caverns.—Fault Caverns.—Wave Caverns: Blue Grotto; Staffa Cave.—Rock House Caves—Lava and other Volcanic Caverns.—Symmes's Hole.

THE surface phenomena of the earth, the scenes which have an every-day familiarity, soon become to ordinary observers commonplace. The sailor finds the ocean tiresome, and the dweller of the Alps sees little to awaken pleasurable emotions in the peaks and glaciers which from year to year meet his eyes. All of us are familiar with the glory of the starlit sky, and know that these points of light are the spheres of planets and suns scattered through fathomless space; and yet this spectacle, which would overwhelm the soul were it disclosed for a single hour in a lifetime, arrests but a momentary interest or, oftener, passes unnoticed at all. It is the unseen which most attracts us. Therefore, in all times men have speculated as to the contents of the nether earth. Its crevices and caverns afford in their dark recesses a world which the imagination can people at its will. Even if they excite only a vague wonder mingled with terror, these subterranean spaces are still fascinating to the explorer

Entrance to the Mammoth Cave Kentucky

weary of the well-known or, rather, familiar objects of the sunlit world.

The class of underground openings known as caverns have, in all countries and at all times, been especially captivating to the lovers of the marvellous; their strange architecture, beautiful ornamentation, and peculiar inhabitants have combined to make them attractive. To men of science they have recently become extremely interesting, because they throw light on the early conditions of savage man, and in other ways make some startling contributions to the facts which bear on the so-called Darwinian theory.

The open spaces of the underground may, for convenience, be divided into several distinct classes: First, we have the caverns, or the channels excavated in limestone rocks by streams which find their way beneath the surface. Next, the channels and chambers hollowed out by the waters of hot springs on their way from the depths of the earth to the surface. Third, come the sea-caves, formed where the battering surges have worn a way into the shore-cliffs along the line of some softer part of the rocks or of an incipient fissure. Fourth, the cavities curiously formed where a lava-stream has frozen or solidified on the surface, while the liquid rock below has flowed on or sunk back into the depths, leaving the arch standing, until the matter which originally supported it has disappeared. Lastly, we have the rifts formed in the rocks which have been rent by the mountain-building forces, where the walls on either side of the break—or, as it is termed by miners, the fault—have been pulled apart from each other, leaving a very deep and long, but relatively narrow, fissure. In one or another of these groups we may place all the known cavities which occur beneath the earth's surface. The variety

of these subterranean chambers is so limited that we shall be able within the compass of this chapter to see something of the history and character of them all.

Owing to their wide distribution, great variety, and vast extent, the limestone caverns are the most interesting of these groups of caves. They occur in all those parts of the earth's surface where thick-bedded and pure limestones lie with their layers somewhere near horizontal, and where, at the same time, the main streams have cut deep channels in the surface of the country. It is also essential that the region should be forest-clad; or, even if now deforested, that it should have been covered by woods at the time when the excavation of the caverns was going on. With these conditions the formation of caverns is necessarily brought about. The rain-water falling on the surface of the decaying vegetation has, when it arrives on the earth, but little power of dissolving rocks of any kind; but on passing through this bed of oxidizing carbon it takes up a large amount of the gaseous material, composed of one atom of carbon and two of oxygen, known commonly as carbonic-acid gas. This absorbed gas gives the water a singular capacity for taking into solution a large amount of lime, iron, and many other substances which are found in rocks.

Descending through the soil, this solvent compound of water and carbonic-acid gas finds its way into the narrow crevices or joint-planes which exist in all rocks. It quickly widens these channels until they are so spacious that the brooks desert the surface and become underground streams, which often course for miles in the hidden channels. At first, while the crevices are narrow, the excavation is altogether done by the dissolving action of the water; but when it has

thus excavated a channel sufficiently large to permit a stream to flow freely through it, the speed of the current through the new-found way abrades the rocks by its mechanical power, at the same time exercising its solvent action. To see the nature and extent of this work, we should go to some district of extensive limestone caverns and examine the action of the

Cave Hill with Sink holes Luray Va

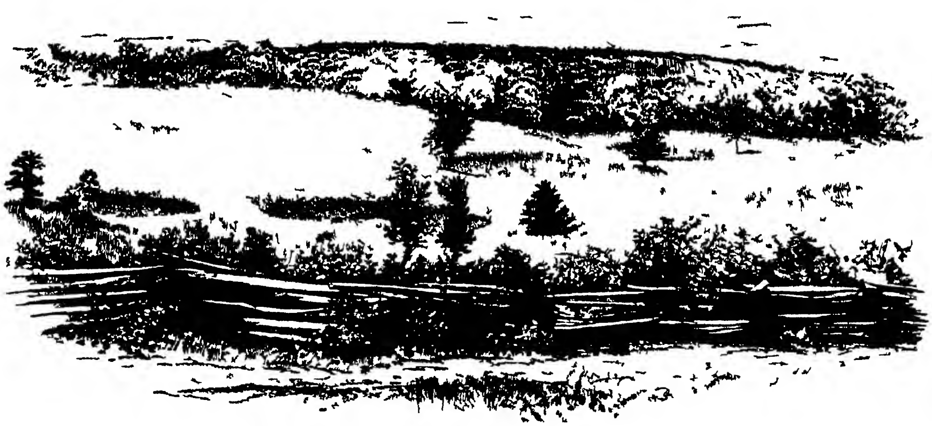
water, from the time when it falls on the surface, along the course of its underground journey, to the point where it emerges beneath the cavern's arch into the main river of the country.

Probably the best region in the world for the study of this interesting geological work is the caverned district about the head-waters of the Green River in Kentucky. In that region the limestones of the Subcarboniferous group of rocks attain a depth of several hundred feet, and are very thick-bedded,

the separate layers or beds being often twenty or thirty feet thick. The pure nature of this limestone, and the absence of divisional planes, such as the thin beds of clay which commonly divide such deposits, are, as we shall see, peculiarly favorable to the formation of wide and lofty caverns. This thickness of the beds is due to a cause which it is interesting to note; for the reason that it shows how dependent the shape of our earth is upon the nature of the creatures that build with their remains the rocks which form on the sea-floor. The greater part of the limy matter in limestones is formed of the remains of animals which lay prone upon the sea-floor. When any great disturbance, such as earthquake-shocks, agitated the water on that floor, the slimy mud which was swept about destroyed over wide areas this population of the sea-bottom. Until these creatures re-established themselves, the sediments which were formed would not contain much lime, but would consist of clayey or sandy matter alone. If this process were often repeated, the resulting limestone would be so frequently interrupted by insoluble layers of other materials that only shallow and unimportant caverns would be developed in them.

There are two ways in which these massive limestones can be formed in the deeper seas: As in the central part of the North Atlantic, where minute limestone-encased creatures float in the water while they live, and at their death give their skeletons to the sediments of the sea-floor; in which way massive limestones, such as the chalk deposits of England, have been produced. Another method in which such deposits are made—the way, indeed, in which these subcarboniferous limestones of the Mississippi valley were formed—is by the following process: Certain of the tenants of the sea-floor—

the corals, and especially the sea-lilies—have stems which lift the mouths of the creatures above the level of the frequently stirred mud; thus they survive the catastrophes which bring death to the sensitive forms whose bodies become buried in the running slime. The greater part of the animals which contributed their remains to these massive beds of lime were of these stemmed groups, and this slight peculiarity has given

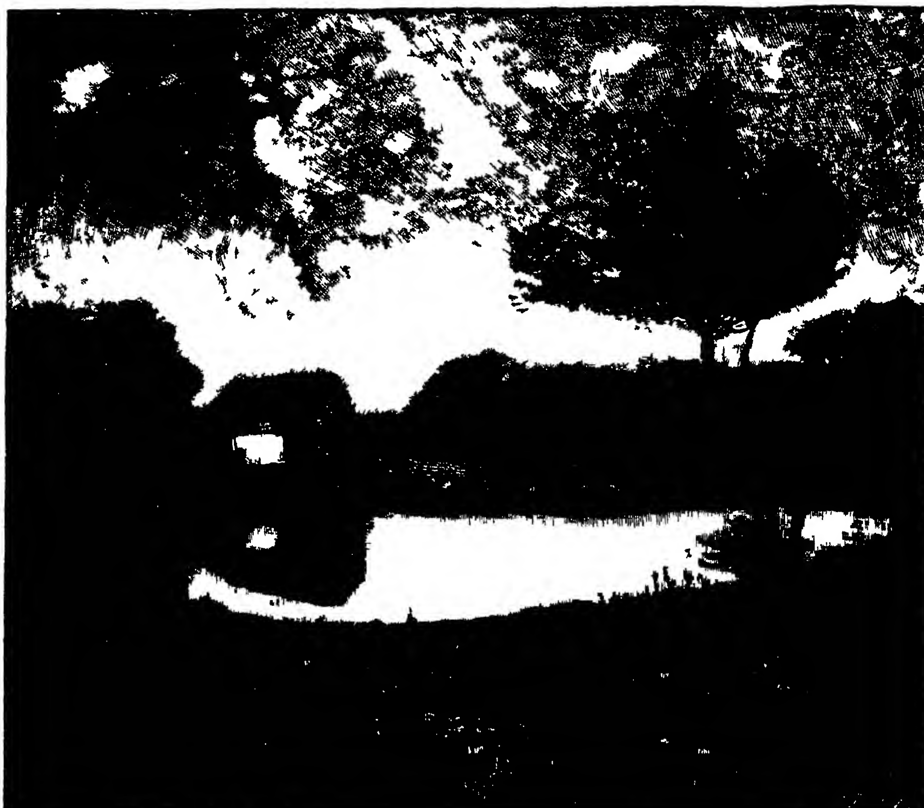


Sink holes Edmonson County Ky

rise to the features which so mark this country over a region of, at least, ten thousand square miles in area.

As soon as the observer comes upon this caverned district of Kentucky he remarks that he has passed from the region where running brooks abound, and is in a country where there are neither streams nor the distinct hills and valleys which he is accustomed to see in other lands. The surface of this area is cast into a series of shallow, circular pits, varying in diameter from a few score feet to half a mile or more. So crowded together are these pits that almost the entire surface

lies in some one of these depressions. In the bottom of each of the pits there is normally a vertical shaft, or a series of crevices, down which, in time of rain, the water flows from the drainage-slope of the pit, or "sink-hole" as it is called in local phrase. Generally these conduits have been closed, by



Sink hole Edmonson County, Ky (The shaft leading down to the cavern has been artificially closed)

accident or design, in which case a little pool of circular outline occupies the centre of the depression. Occasionally, in place of the sieve-like openings which usually give the rain-water passage to the depths of the earth, the opening is large and circular, resembling the entrance to a well. Such openings were once common in this country, but the cattle,

tempted by the rich herbage which commonly grew about the damp borders of the pit, were often entrapped in the opening, so the greater number of them have been artificially closed. Now and then in the remaining forest-areas we may find these shafts still remaining open, offering the way for daring explorations, which we are about to invite the reader to follow in his imagination.

The ordinary visitor to this region of caverns enters the few show-caves in the convenient way afforded by some break of their roofs, or by the old places of exit of the caverning streams. In actual practice we commend this conservative custom; but as our imaginary journey demands only ideal risks, we may now proceed to follow the history of the process of cavern-making, from the place where it begins to the point where the waters conclude their underground work and enter the open streams.*

*Making a simple, strong frame over the opening, to hold a hoisting-block, and passing a strong rope, some hundred feet in length, through this block, the explorer will have the means of descending to the nether world. It will be well for him to take the precaution of fastening the rope around his left ankle, with a well-arranged slip-knot, and then place the same foot in a simple stirrup-loop of the rope. Thus, in case he should by any chance lose hold of the rope, he cannot fall into the depths. A signal-cord should also be provided, by which the explorer can send the simple commands of *lower, stop, hoist;* for the depth and width ot the vault into which he descends may be so great that his voice will be lost in the space or confused by reverberation. This cord should be fastened to the waist, and should be led to one side of the opening, so that it may not become wound round the main rope. In practice it requires four trusty helpers to manage this exploration—three to control the rope, and one for the signal-cord. In fact, it requires five people who are not apt to become nervous, for the explorer himself should be a calm-minded person.

The explorer should take with him an oil-lantern, holding six hours' supply; at least two candles, well fastened in his pockets; and two water-proof match-boxes, and some bits of magnesium-wire or bengal-lights for illumination. A stout staff

With proper precautions, the most important of which are indicated in the foot-note, the adventurous person may descend these pits with no more risk than he encounters in Alpine mountain-work. In this country, where untrodden heights are not open to us, it may be worth while for the lover of adventure to try these cavernous depths. The present writer, who has tried both kinds of exploration, is inclined to consider the cavern-work as, perhaps, the more fascinating of the two. Certainly, the explorer more quickly finds his way into the realm of the unknown than in mountain-climbing, and is less often met by the discouraging evidence that, after all, the ground is not untrodden.

The first thing we note on entering the throat of the chasm is that, if it be warm weather, there is a decided current of air setting down into the space below; if it be cold, there is an ascending current of warm air from the shaft, which condenses into mist as it escapes from the opening. The meaning of these currents we shall see when we come to consider the movements of the air in caves.

Descending a few feet into the chasm, we note that the shaft rapidly widens on every side, so that in most cases we quickly lose sight of the bordering walls; the structure of the shaft is, indeed, that of a rude dome, of which the hard layer at the top forms the capstone. After going down a little distance, the width becomes so great that the scant light of a single lantern may not disclose the sides of the arch. At a depth of a few more feet, we find that the pit again contracts, a great shelf extending from the sides to near the

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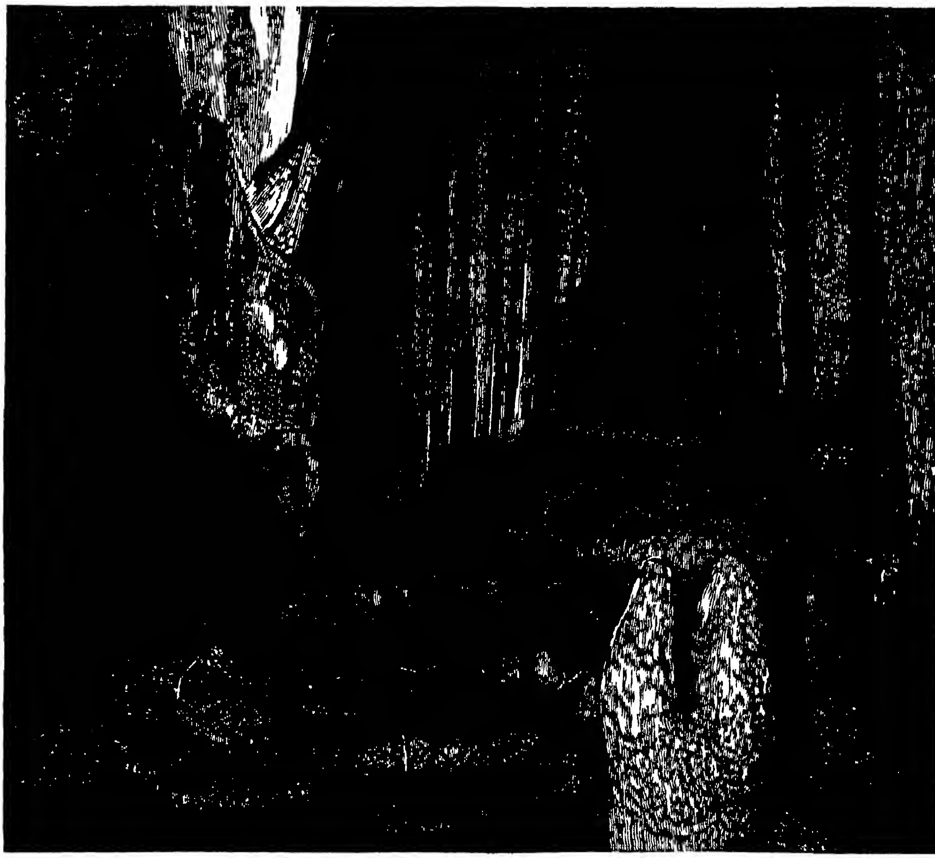
with a thong, by which to hang it to the waist, will be useful. Care should be taken that the rope is several times as strong as is required, and that it has no tendency to spin round when a weight is put upon it.

centre, through which there is a passage rather wider than that at the orifice. Landing on this shelf, we find it to be a tolerably level floor, from which spring the walls of the upper dome; from one or more sides of it extend galleries, whose floors lie on this harder layer—their arches excavated



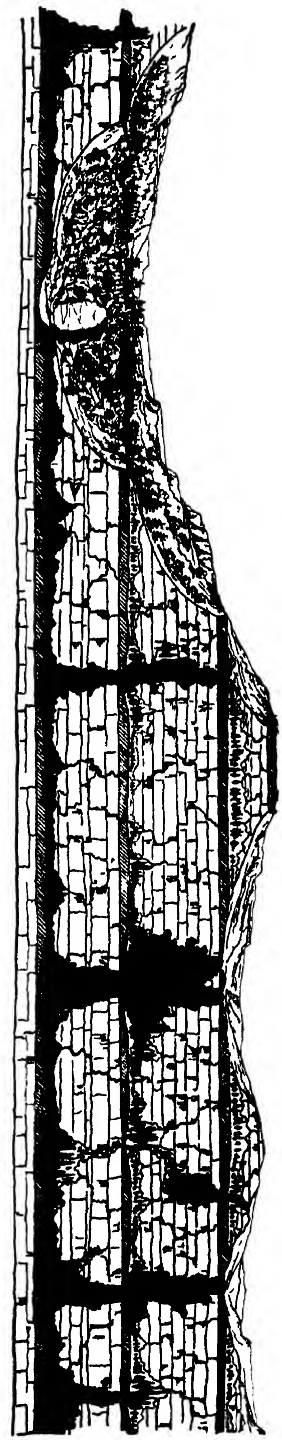
Stalactites Luray Cavern (Engraved from a photograph by C H Janes)

in the softer overlying rock. We see at a glance that these channels were once the paths of streams, though they have not for ages been occupied by their waters. As we follow down the wandering gallery, we find that it is joined by many similar passages, the whole forming a labyrinth in which the unwary explorer may easily become confounded. Each of

these passages terminates in a vertical shaft, or rude dome, essentially like that by which we gained access to the cavern, but generally communicating with the external air by passages so narrow and tortuous that they do not admit the light. We can see that as this main channel is joined by the side passages it constantly increases in size, until, perhaps, it attains majestic dimensions. We may travel through it for miles, until we are suddenly arrested by some one of several classes of obstacles: A great fall of stones from the roof may close the way; or through the hard layer which constitutes the floor the water may have found and enlarged a downward passage, creating a dome like that which we descended; or, more frequently, an assemblage of crowded stalactitic pendants and columns close the once open space as with a wall of resplendent crystals. Returning to the main dome, we may continue the descent toward the lower level of the cavern. In the depth below the first level of galleries we find several others, each having the same general character, and all, in turn, deserted by streams, each with the infinite variety of detail given by the eddying current of the vanished streams and the trickling waters which bring in the stalactitic materials. Finally, we come to the floor of the cave, and commonly land in a considerable pool of water, partly filled with angular fragments of flint. In times of heavy rain, when the waters pour down this great shaft, these fragments of hard stone are set into tumultuous motion, and for a time rapidly work through the hard floors which the shaft encounters in its downward progress. There is, however, a limit to their wearing action; for when this pool attains a certain depth the water it contains forms a cushion to receive the blow of the cataract, and so arrests the erosion. Until the vertical shaft is deepened, the

water finds its way, as in the upper levels, horizontally along the surface of the hard layer to its next downward plunge, or until it escapes into the open streams of the country.

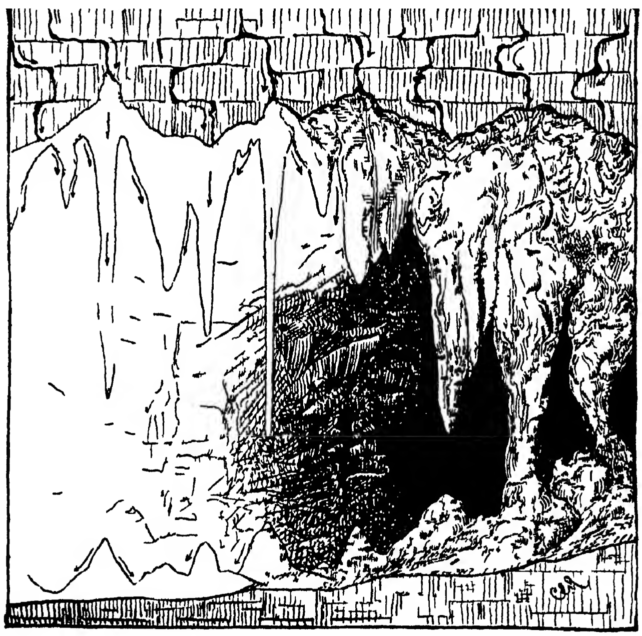
As this action is repeated in a small or a large way by all the streams which enter the earth at the bottom of the sink-holes, it is easily seen how the rock, for all the depth, from the highest land to the level of the principal rivers, becomes in time converted into a vast tangle of shafts and galleries, so that the mass often resembles a piece of worm-eaten wood, the greater part of the strata having been removed by erosion. Thus, within a section of, say, ten square miles, and a thickness of three hundred feet, in which lies the Mammoth Cave, there are probably in the known and unknown galleries more than two hundred miles of ways large enough to permit the passage of a man, besides what is probably a greater length of smaller channels. Within the commonwealth of Kentucky, principally in the subcarboniferous limestone, it seems certain that there is an aggregate length of such underground galleries exceeding many thousand miles. The total



Showing the Formations of Caverns in Limestone (In the distance a natural bridge, the remains of a great cavern.)

amount of these underground passages would be much greater, were it not for the deposits of stalactitic matter which take place in them, and which, in many parts of the caverns, rapidly work to close the openings as soon as they have been deserted by the channelling streams.

The stalactizing process is brought about by a modification of the very same action to which the original formation of



Stalactite Formation in Limestone (The arrows show the direction of the movement of the water.)

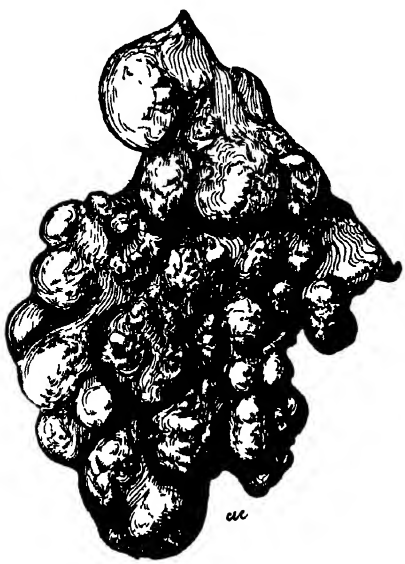
the caverns is due—viz., to the power of dissolving limestone given to water by the carbonic-acid gas which it obtains from the decaying vegetation. When this water finds its way through an open channel, it dissolves the rock and bears the suspended lime speedily away; when, however, the water has to creep through narrow interstices, it advances very slowly and in small quantities. Encountering the space of a cavern in its downward passage, it oozes, drop by drop, through the

roof or into the crevices which lead upward from it. As there is a constant, though slow, circulation of air through these caverns, they are generally dry, and this exuding water may evaporate without falling to the floor, leaving where it dries the various dissolved substances which it contains. In this way a slender, pendant-like body begins to form on the ceiling, and grows with varying speed toward the floor. If the incoming water is greater in quantity than can be taken up by the air, it drops from the hanging stalactites. When it strikes, the drops are shattered. Evaporation and the loss of the carbonic acid causes a still further deposition of the dissolved matter, which crystallizes in a conical heap, growing upward to meet the corresponding descending cone. As the water commonly penetrates, not at one point, but along the irregular line of crevices, these stalactites are usually in the form of coalesced columns, which in time form a continuous sheet which may extend entirely across the space of the gallery. If there be many fissures in the roof, the gallery may in time become quite closed by the conjoined sheets of stalactitic material. This process of depositing lime goes on most actively in the upper or oldest levels of the cavern, for the reason that they are nearest the surface and, therefore, to the supply of the carbonated waters; the lower levels of the system of caves are generally destitute of them, the percolating water having found its way into the upper chambers. Besides the beauty which this stalactitic material gives to caverns, we owe to these sheets of lime the preservation of the various fossils which are entombed in the caves.

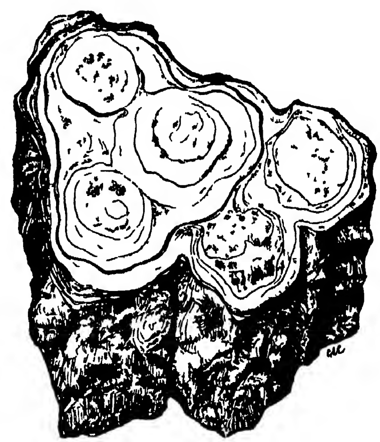
It is interesting that so small a circumstance as the speed with which the water flows through the interstices of the rocks can thus profoundly affect the method of its action. Where

it goes swiftly, it excavates the caves; where, moving slowly, it penetrates a large opening, it tends to obliterate the cavern. This is but one of many cases in natural phenomena where slight changes in circumstances totally alter the results of processes.*

There is a curious destructive effect sometimes exercised by the formation of stalactitic material. It occasionally



A Stalactite



Cross-section of Stalactite (Produced by several separate stalactites growing together)

happens that these accretions, particularly those composed of gypsum, gather in the crevices of the rock which forms the roof of the cavern. Slowly accumulating, these stalactitic masses wedge the rock apart and finally destroy the adhesion of the blocks which constitute the roof. These separated

* It is commonly supposed that stalactitic deposits are peculiar to caverns, but they may be seen wherever massive brick arches are exposed to percolating water; the lime of the mortar passes into solution, and forms small pendent deposits exactly resembling those of caverns. Other substances, such as the iron ore called limonite, also occasionally form beautiful stalactites in the small cavities in ore-beds exposed to the leaching action of percolating water.

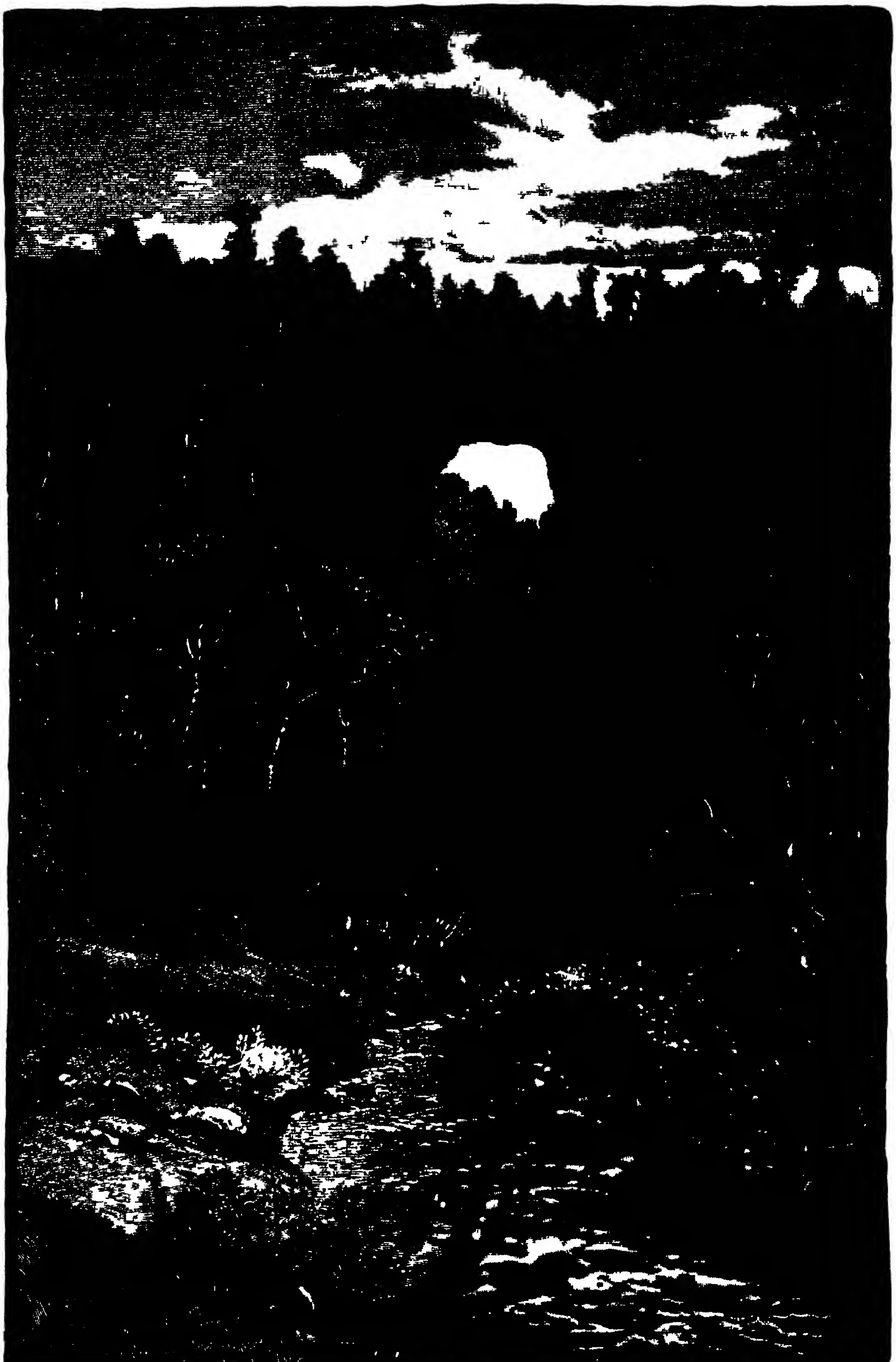
masses fall to the floor of the chamber, exposing other layers to the same process of dislocation. In this manner certain caverns which may have been formed at a low level slowly rise upward towards the surface, until the roof is carried to the air or until the loose fragments which cover the floor have

Stalactites Luray Cavern (Drawn from a photograph by C H Janes)

accumulated to such an extent that the space is actually closed. If the chamber of the cavern is the seat of a free running stream, it may dissolve or break up and bear away the fragments, and so preserve the space of the chamber.

We have already seen that in any great district of caverns we usually have the underground spaces divided into distinct

floors, of which the uppermost was the earliest to be constructed. In such a district the open-air rivers are constantly cutting their channels deeper into the earth, thus preparing the way for the formation of yet lower levels of galleries; at the same time the general surface of the country is wearing downward, only at a slower rate than the stream-beds of the open-air rivers. If the beds be nearly horizontal (it is only in such districts that we have very extensive caverns), the descent of the upper surface is greatly restrained by the presence of the insoluble layers which we found to make the throat of the vertical shafts, or domes. It is often a very long time, even in a geological sense, before the slight surface-erosion acting on a sink-hole country can wear through this roofing-layer. In time this is accomplished, and the uppermost chambers are bared by the destruction of their roofs. Commonly these ruined galleries are filled with the *débris* of the roofs, in so far as they have not previously been closed by stalactitic matter. It often happens that the roofs do not altogether fall in at once, portions of the arches remaining standing for ages. These constitute the "natural bridges" which are found in all cavernous countries. Sometimes the greater portion of the arch remains, in which case we may, as in some instances in Kentucky, have a momentary view of a considerable underground river, or gain access to a great system of underground chambers which would otherwise be unknown. The Mammoth Cave, for instance, is entered by such a tumble of the roof of a gallery; and, notwithstanding its vast length of connected chambers, there is no other practicable way into its recesses. Again, we may find a stream suddenly vanishing beneath a dark archway, to reappear after a course for many miles underground. When a small part of the arch alone



Natural Bridge Virginia

remains, the structure takes the form of the well-known Natural Bridge of Virginia.

In almost all cases these natural bridges have free streams beneath them, which bear away the fragments falling from the roof, and so permit the chamber to grow almost indefinitely in height, until the material of the roof no longer exists.

When the remaining portion of the arch is too wide for the term "natural bridge" to be suitable, the appellation "natural tunnel" is often applied to the passage. There are several passages of this nature in the Eastern United States, of which the finest is, perhaps, that near the Clinch River, in Virginia, where a considerable mountain-stream flows through a vast arch for a distance of over half a mile. This natural way is about to be used for the passage of a railway.

Let us now turn to the physical features of the caverns other than those which are involved in their production. Among these we note the circulation of air through the caves. This is a beautiful and often startling phenomenon. If on a hot summer day we approach the lower exit of any great system of connected caverns, we are surprised by the swift, cold wind which pours from its mouth and inundates the valley below with the chill air. In Kentucky this air always has the temperature of about 60° Fahr., the mean heat of the upper earth, and thus often affords a striking contrast to the external temperature. In the summer season this air is derived from the many small currents which pour in through the sink-holes in the high ground. It is cooled in the vast chambers through which it slowly moves, being, on the average, some months in its journey, and finally escapes at the lower vents of the cave. When the temperature of the outer atmosphere is low, the current is reversed, entering then

through the passages along the rivers, and finding its exit, as warmed air, from the myriad crevices of the uplands.

In consequence of the slow passage of this air through the cool, dry caverns, where there is almost no decomposing organic matter, it acquires a remarkable purity, which in warm countries is only found in the midst of great deserts. We have a sensible experience of this purity when, after a summer's day in a great cavern, we come suddenly into the warm air of a forest. For a while the rank odor of the vegetation is most unpleasant. We marvel that men can live in such an impure element as the air seems to be. A more satisfactory proof of the purity of the cavern-air is found in the absence of decomposition in animal bodies exposed in the inner recesses of caves. Even large animals fail to pass through all the stages of putrefactive decay. A few years ago the body of a young Indian was found in a mummified state in a dry portion of one of the caverns near the Mammoth Cave. The unhappy child had probably wandered away into the darkness, and when overcome by starvation had lain down on a shelf of rock for the sleep of death. Naturally the body was much emaciated; but the skin was unbroken, and even the face as little altered as in a well-preserved Egyptian mummy.

These qualities of dryness, invariable temperature, and purity of the air in the Mammoth Cave have long been remarked. At one time a rude effort was made to use this cavern-air in the treatment of pulmonary consumption. A number of huts were constructed in the main avenue of the cave, which were for a time occupied by several persons suffering from this disease. As may be imagined, the results were most unhappy. The absence of sunlight, combined with

the sombre surroundings, hastened the progress of a malady which under no circumstances could have been materially helped by the qualities of the air. This unhappy experiment has led to a neglect of the proper methods of using the peculiar hygienic qualities of the air of caves. This can only be accomplished by pumping the air from the cavern to a properly constructed sanitarium on the surface of the earth. With the modern ventilation-fans this can easily be effected. Choosing a point where the supply would be taken from the large chambers of a cavern, like the Mammoth Cave, some miles from the entrances, a very large building could be supplied with air of a perfectly uniform temperature and exceeding purity. There can be no question that a hospital arranged for this purpose would afford admirable conditions for the treatment of certain classes of maladies, especially where it was desirable to exempt the patient from the heat of summer, from the irritating emanations of vegetation, or from malarial poisons.*

The relation of primeval man to caverns was much closer than that of his civilized descendants is ever likely to be. Before the savage began to be a constructor of dwellings, caves afforded him a natural and, in many respects, a satisfactory abiding-place. At their entrances he often found a dry chamber, which could generally be defended to advantage; the recesses of the cave afforded places of refuge in case of disaster. In the Old World caverns appear to have been much more commonly occupied as dwelling-places than in the New. In any part of Asia and Europe where the caverns have been explored they have given evidence of occupation

*The Trocadéro Palace in Paris is, I believe, provided with a system of pipes by which the air from the quarries beneath that city is used for cooling the edifice.

by the ancient races of man. Some of the most ancient remains of the bodies and the arts of those peoples have been disinterred from beneath the stalagmitic sheets which have preserved them.*

In North America the caverns do not appear to have been, to any extent, used as dwelling-places by the aboriginal peoples. Though often resorted to, in but few cases do they appear to have been continuously occupied as were those in Europe. This is perhaps due to the fact that the first ancestors of our Indians who came to this country had already attained an advancement in the arts which enabled them to make shelters of a more convenient sort than caverns afforded. About the only considerable use which our American Indians made of these caves was as burial-places. They appear sometimes to have made a rude disposition of the dead, or perhaps even of their prisoners of war, by casting them down the shafts which lead to the caverns. More commonly they used the deep layer of fine, dry earth so often found in the caverns for deliberate and careful burial. Lighting their path with torches made of cane-joints filled with tallow, they appear to have wandered far into these caves, seeking for flints which abound there, or perhaps trailing their escaped enemies to their hiding-places. Occasionally in the innermost recesses of these caverns we come to a place where one or more persons have long lain concealed, as is shown by the remains of food or clothing which have been left behind. Often, when it appears as if we had penetrated to some recess never before trodden by man, we find on the cavern-dust the footprints of a savage predecessor, which, though made perhaps centuries

* For a good general account of these cavern-dwellers, see Professor W. Boyd Dawkins's "Caves and Cave Hunting."

ago, remain so fresh in this immutable realm that we might expect to encounter him on our way.

The caverns contain the remains of many other animals besides primitive man. In Europe many of these caves are singularly rich in vertebrate fossils. There are two ways in which these fossils are brought into the caves. The sink-holes are, as the farmers of Kentucky have found to their cost, natural traps into which the unwary beast may fall. The bones of these creatures are swept on by the current until, becoming lodged in some crevice, they may be preserved. A more frequent source of these fossil remains is the habit of certain beasts of prey, which leads them to drag the bodies of their victims into their cavern-lairs that they may devour them at their leisure. The Old World hyena and the jackal, having been generally associated with larger predaceous beasts, such as the lion and the tiger, were compelled to adopt this habit to protect themselves in their repasts from their stronger rivals in the chase. In this way the wonderful accumulations of gnawed and scattered bones which characterize the European caverns have been brought together. In North America the carnivorous mammals, much fewer in number than in the Old World, have never adopted the use of the caves as lairs. Jackals and hyenas have never been known here; hence in American caverns we have a relatively small amount of bones in the deposits of the cavern floors.

The living inhabitants of caverns, those which make these regions of continuous darkness their abiding-places, are numerous and of the greatest interest to the naturalist. Of the several hundred species known to students, by far the greater part belong to the group of articulated animals, insects, and crustaceans, these being the forms which, of all

animals, are the most varied in structure and best suited for the peculiar chances of life which the caverns afford. As the reader well knows, the great problem now before science is to determine how far the shapes of living creatures are determined by the circumstances of the world about them, and how far this determination has been brought about through a process of selection, in a natural way, of those varieties which have some accidental special fitness for the conditions in which they live. Cavern-animals afford us a capital bit of evidence toward the solution of this problem. The prevailing close affinity of their forms with those which live in the upper world of sunshine and changing seasons shows, beyond a question, that they are all derived from similar forms which once dwelt in the ordinary conditions of animal life. What, then, are the effects arising from this complete change in the circumstances of these underground creatures?

The facts are perplexing in their variety, and a consistent theory of them by no means well worked out, but the following points seem to be well established, viz.: There is a manifest tendency of all gayly colored forms to lose their hues in the caverns, and to become of an even color. This may be explained by the simple absence of sunshine, and on it no conclusions can be based. The changes of the structural parts are of more importance; these, as might be expected, relate mainly to the organs of sense. The eyes show an evident tendency in all the groups to fade away. In the characteristic cavern-fishes they have entirely disappeared, the whole structure which serves for vision being no longer produced. In the cray-fishes. we may observe a certain gradation. Some species which abound in caverns are provided with eyes; others have them present, but so imper-

fect that they cannot serve as visual organs; yet others want them altogether. One species of pseudo-scorpion, as shown by Professor Hagan, has in the outer world four eyes, while in the caves it has been found with two eyes, and others in an entirely eyeless condition. Some cavern-beetles have the males with eyes, while the females are quite without them. As a whole, the cavern-forms exhibit a singular tendency of the visual organs, not only to lose their functions, but also to disappear as body-parts. At the same time there is an equal, or even more general, development of the antennæ and other organs of touch; these parts become considerably lengthened, and apparently of greater sensitiveness, a change which is of manifest advantage to the individual.

It is probable that the organic species which inhabit our caverns have generally been, for some geological periods, existing in the peculiar conditions of caves. Thus, in the Mammoth Cave district of Kentucky, or the neighboring fields of Tennessee, the present levels of the subterranean chambers have probably inherited their animal life from stages or stories of the caves which have since been destroyed by erosion. In some regions the geologists can show that above the level of the existing caverns, for the height of a thousand feet or more, in what is now mid-air, caves probably have existed in former geological periods, which have slowly been worn down by atmospheric decay. On these former levels of caverns, through geological ages, the organic species have been undergoing variations which have gradually changed them from their ancestral forms.

The bearing of these changes on the Darwinian theory is as follows: That hypothesis, at least in the form in which it is generally held, considers that the important changes in

organic species are the results of a successful struggle for existence of creatures possessed, through a chance variation, of some slight advantage over their kindred. The difficulty which the objectors to this view find in their way is that, in the perplexing variety of conditions of the outer world, it is wellnigh impossible to say that this or that peculiarity is not of great advantage under some circumstances, the selective effects of which are not manifest to the observer. The admirable feature in this great natural experiment, which is brought about by the imprisonment of organic forms in caves, is that it very much limits the speculation-breeding confusion of the outer world. Thus it at once becomes clear that the loss of eyes cannot well be the direct result of any selective action; it must arise from the immediate influence of the darkness. It is scarcely less clear that the corresponding development of the tactile organs must be due to something else than selection; for the cavern-life, at best scanty in any one cave, cannot be conceived to afford the conditions of strenuous battle which exist in the overground world. It must not be supposed that this evidence goes to overthrow the fundamental propositions of the Darwinian hypothesis; it only shows that we must carefully limit the action of the "survival of the fittest," and that we must be prepared to allow a large share in the development of organic forms to forces which have nothing to do with selection,—to the innate organic impulses, or to the immediate action of environment.

A word concerning the geographical distribution of this group of superficial caverns, and we shall have done with this division of our subject. So far as the present writer has been able to observe American caverns, they have been limited to the regions south of the vast field occupied by the ice-sheet of

Brand's Cascade Luray Cavern (Drawn from a photograph by C H Janes)

the last glacial period. But in New York and elsewhere there are some small caverns which were within that field of ice. It is an important task for students to find whether these caverns existed before the ice-period, or whether they have been formed since that time. If they survived the glacial period, as seems likely, then they afford valuable evidence to show that the ice did not wear away as great a depth from the surface of the country as is commonly supposed.

The second group of caves exhibits a certain general resemblance to those just described. These are the caverns which have been formed by hot waters on their way to the surface, where they emerge as hot springs, or geysers. These hot spring-waters are in the main rain-water which has penetrated to great depths below the surface, and become heated by the internal temperature of the earth ; this rain-water is more or less commingled with the old sea-waters which were built into the strata through which it has passed in its slow underground journey. Unlike the cavern-making streams which excavate the superficial caves just before described, these spring-waters rising from the depths of the earth do their work by ascending currents, with no direct help from gravitation ; their action is therefore not mechanical or erosive, but chemical or corrosive. They do not tend to excavate a succession of galleries, one above the other, but work to open single channels of escape. When in their upward path they encounter deposits of limestone, they rapidly enlarge the spaces through which they flow, making great chambers where the rock is soluble, connected by narrower fissures through the less soluble parts of the deposit. The solvent power of the water is in part due to the carbonic-acid gas it obtained from the decayed vegetation before it started on its

downward journey, and in part to the further contribution of this and other gases given to it by the various decompositions going on in the heated depths of the earth. The elevated temperature of the water also aids its work of corrosion.

In the superficial cold-water caves, as we have already seen, the caverning cannot go on at depths below the general levels of the main streams of the district in which the caverns lie; but in these hot-spring caves the excavation can go on at depths of miles below the surface. Springs of this nature are particularly characteristic of mountainous districts, where the strata lie at high angles. They are also found in regions where volcanoes are or have recently been in action. It is easy to see that either one of these conditions favors the development of such hot-water caverns. In the mountainous districts this is effected by the presence of rifts in the rock, or of highly inclined porous strata, which conduct the surface-waters to great depths. In these depths the rocks are highly heated by the internal temperature. Partaking of this internal heat, the water passes upward through any chance way leading to the surface. In volcanic districts the water, after a much shorter downward journey, may find itself in contact with masses of lava or rocks which are at a high temperature because they have recently been traversed by volcanic fires.

We note that at the mouth of these hot springs and geysers, the waters of which have passed through limy rocks, there is a very extensive deposit of lime, which is laid down at once as soon as the temperature of the solution falls by exposure to the open air. These hot-spring deposits often constitute very extensive accumulations of rocky material; as, for instance, in the Yellowstone district. They afford a rough indication of the cavern-making power of the waters on

their way to the surface. It must, however, be remembered that only a portion, probably much less than half of the dissolved rock, is laid down at the mouth of the spring; a larger part passes to the rivers, and thence to the sea.

Our knowledge of these hot-spring caverns is not altogether theoretical. It happens that the abandoned channels of these springs are often the seat of important deposits of the precious metals, which has led, in this country, to their becoming the seat of extensive mining operations. There are at least half a dozen extensive mines which have followed these cavern-deposits in the district of the Rocky Mountains; it is likely that there are very many others which await the explorer. The origin of these mineral deposits is probably as follows: After the heated waters have excavated the caverns, and ceased to flow with their original speed, the chasms become the place of deposit of mineral matters which are brought into them by the creeping movement of waters moving up from below or oozing out from the rock on the sides of the cavity. While the stream of water flowed rapidly upward there was no chance for the chambers to become filled with mineral materials; as soon as the currents were arrested, the mineralizing process would begin. The reader will note the likeness which exists between this process and that by which the abandoned upper chambers of the cold-water or superficial caverns are filled with stalactitic material by the creeping into the chambers of water charged with dissolved substances; the only important difference being that in the superficial caverns the water, being cold, can only take out of the rock and convey into the gallery the very soluble limy materials, while in the deeper caverns the heated water can transfer many less soluble mineral substances.

In the cordilleran district of North America, hot springs are still of common occurrence, and have been more abundant in former geological ages since these mountains were formed. The result is that the mineral deposits formed in such chambers are of considerable economic importance as well as of much scientific interest. It seems probable that a careful search of this region for accumulations of this nature will hereafter develop a great number of deposits of this class which are as yet unknown. There are several reasons why cavern lodes are likely to escape observation. In the first place, while in ordinary fissure veins the lode has a great linear extension, and thus is apt to outcrop at many points; then, in the case of fissure veins, the material filling the cavity is commonly either harder or softer than the surrounding rocks, and so the lode appears either as a ridge or a trough upon the surface of the country; furthermore, in the commoner class of veins, the mineral matter is likely to be in a compact form, which remains in the form of conspicuous fragments on the surface and so affords a "blossom," or trail, which the prospector can readily perceive; in cavern mines the deposit will appear on the surface in the form of a small opening, which is readily concealed by superficial material. The substance filling the chamber is in many cases of a very soft nature, and so completely disintegrated as to leave no superficial indication of the presence of the ore masses which lie below. I am satisfied that a careful search for cave mines is likely to prove in a large measure profitable to skilful and enterprising prospectors. I therefore venture to indicate a few conditions which may possibly lead to a successful search for this class of deposits.

Cave lodes commonly occur in regions where limestone

deposits of considerable thickness are found. They most generally appear either where such rocks are riven by faults or where the beds dip at tolerably steep angles. Hot-spring deposits, such as excavate caverns and charge the chambers with mineral deposits, generally form considerable accumulations of what we may compare to stalactitic matter on the surfaces near the point of escape. If the hot spring has not long ceased to flow, it may be possible to identify the site of these mines by the remains of such accumulations, which may thus give the clew to the occurrence of hidden cavern chambers. Inasmuch, however, as these accumulations of "sinter" are generally thin, they may have been destroyed by superficial agents of erosion, the rain, the streams, or the action of ancient glaciers ; therefore, their absence should not be taken as indication that cave deposits are wanting in a given district.

That cavern mines are abundant in the Rocky Mountains, though as yet but few have been found, is shown by the curious nature of the chances by which they have been discovered. Thus, one of the most interesting of these deposits, a lode which has proved quite valuable, was, I am credibly informed, discovered in the following curious manner: A miner dreamed that, if he dug into a limestone cliff, he would find an ore deposit. He proceeded to run a tunnel into the unprofitable looking rock, and at the end of a long and profitless experience found himself in a chamber which contained a considerable deposit of ferruginous clay which held a profitable amount of gold. Although a single instance of this sort does not prove much, it seems to indicate that the limestone districts of the Cordilleras, especially those portions of the country which have been the seat of hot-spring action, should

receive more attention than has been given to them by mining prospectors.

It is probable that the class of cave mines exist in other countries, but, owing to the fact that the combination of hot springs with thick limestone deposits of a multifarious character is seldom found, they are probably among the rarer classes of mineral veins, and, therefore, have not been much studied by mining geologists or noticed by ordinary prospectors.

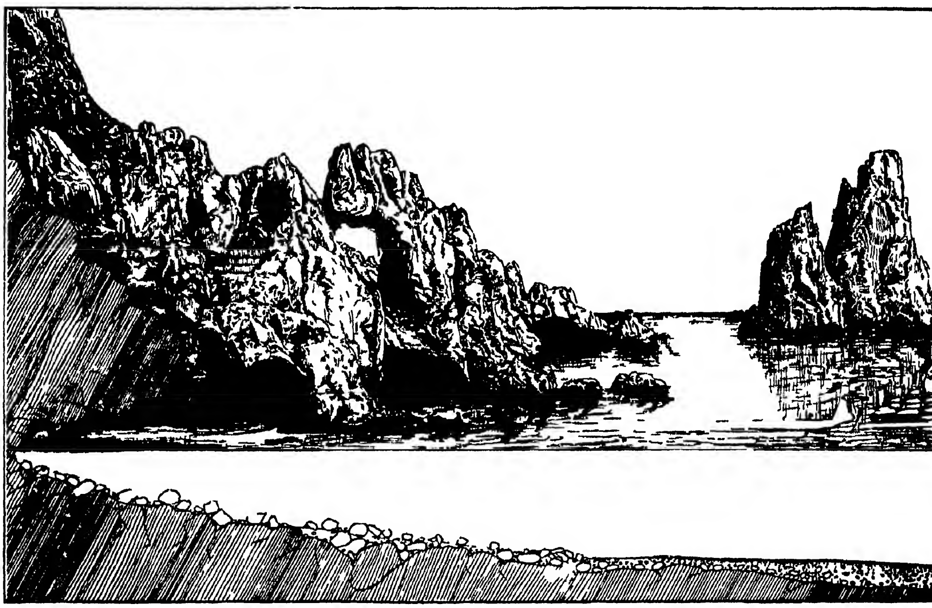
In mountainous countries, where, by the folding and shoving about of the rocks, the strata have been subjected to rending strains, we find another class of subterranean crevices, which may be confounded with the hot-spring excavations. These fault-fissures contain by far the largest number of mineral deposits which are explored for the precious metals. They are generally in the form of very long cracks, which extend horizontally and vertically for great distances, but are usually very limited in width. A tolerable idea of their form and nature may be gained by studying the fissures in walls which arise from the settlement of their foundations, and those which form in timber from the drying-out of the sap. We see that the crevices in walls are due to the down-slipping of the materials on one side of the fracture, thus making a very irregular fissure; while in the fissured wood there is no movement of the two sides past each other, the walls simply gaping apart without other dislocation. In most cases both these classes of earth fissures are filled with mineral matters sweated out from the side walls, or brought up from below as fast as the crevices are produced; so that hardly any space is ever formed, or if formed is quickly filled with vein-matter. But where the rocks are dry these rents may remain unfilled.

In parts of the Rocky Mountain mining-regions the explorer occasionally finds his drills penetrating one of these cavities. Breaking through the wall, the space may be found to have a width of several feet and an indefinite extension downward and on either side. Sometimes the walls are thinly coated with a vein-deposit, formed before the waters abandoned the cavity; in other cases they remain bare, as when they were first rent apart. Even the hardy miners, accustomed to the mysteries of the underground, recoil from the risks of exploring the strange depths of these fissures. There seems to be little chance that they may lead to mineral deposits of value, for the reason that they have never been the seat of the actions which build such deposits. The only use the miner makes of them is to cast the rubbish of his excavations into their cavities. It is greatly to be desired that some of these fissures should be thoroughly explored, for thereby we are likely to gain much knowledge as to the conditions of fault-chasms before they become the seat of mineral deposits.

It has already been said that the caverns scoured out by heated waters have frequently been confounded with these dislocation-fissures. There is good reason for this confusion; for the hot springs, on their way to the surface, generally make avail of such fractures, enlarging them, when they pass through limestone-deposits, into the spacious openings of caverns, and occasionally filling with mineral deposits the parts of the fissure through which the water does not move with speed. We may therefore amend our statement concerning the hot-spring caves, by saying that the caverns of this group are generally local enlargements of fissures when they extend through limestones. In the ordinary fissure-vein deposits we may find traces of caverning, even in rocks which are much

more resistant to the action of heated waters than are the limestone-deposits.

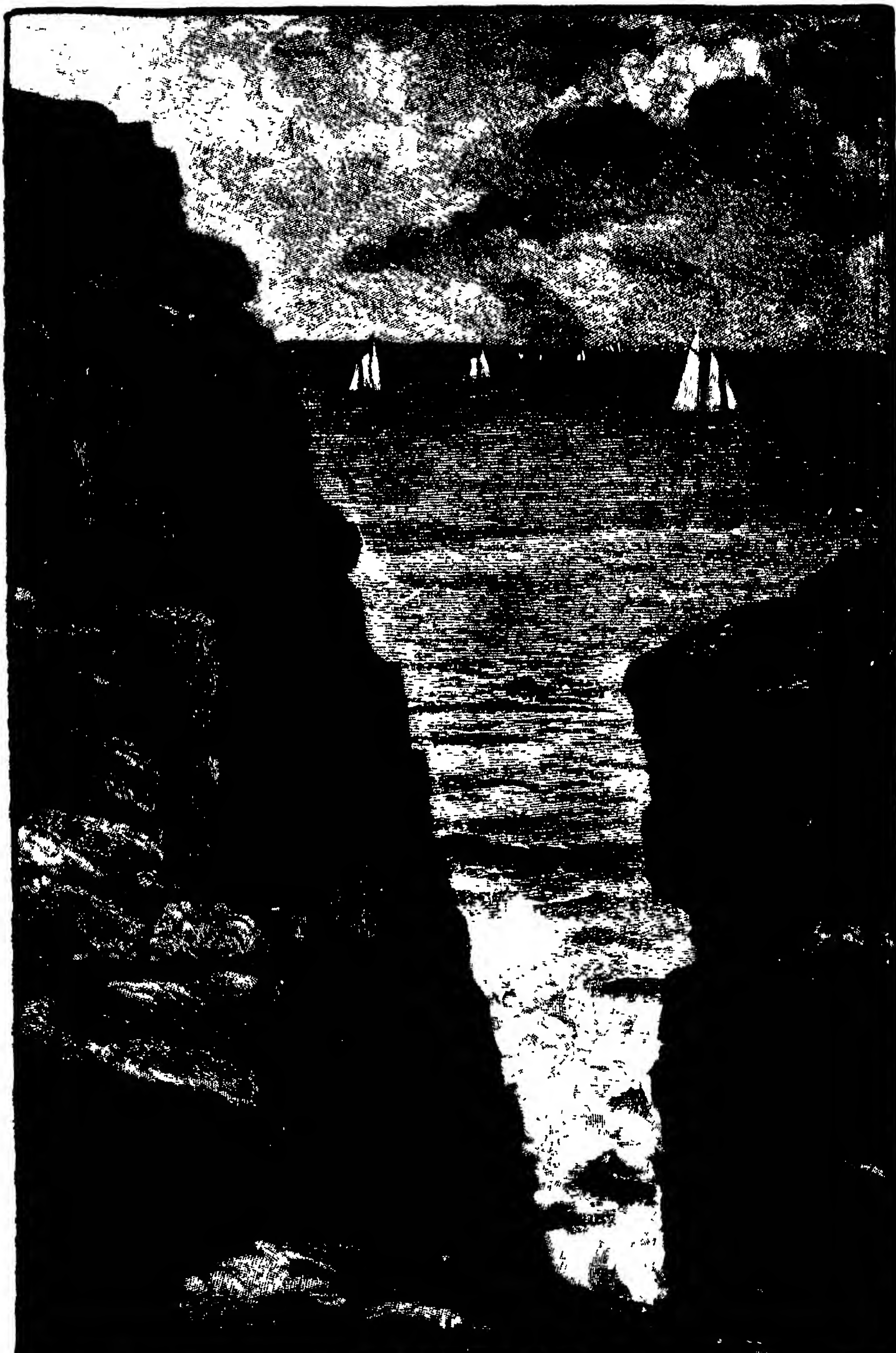
We have now to consider a class of caves which are the result of water-action, but of water operating in an entirely different way from the underground streams. The caverns of this our last division of water-made caves are formed by the beating of the waves against the cliff-bordered shores of lakes



Sea-shore Cave (Showing action of the sea at different levels.)

and seas. The reader has probably seen some examples of this peculiar form of caverning, or at least is familiar with the blow which the waves strike against the shore. At the outset let us gain an idea of the way in which this force of the waves is committed to them, and by their motion applied to the land.

It is well known that this force is due to the friction of the wind against the surface of the water, causing the water to oscillate in somewhat the same way in which the fiddle-string vibrates when the bow is drawn over its surface. In



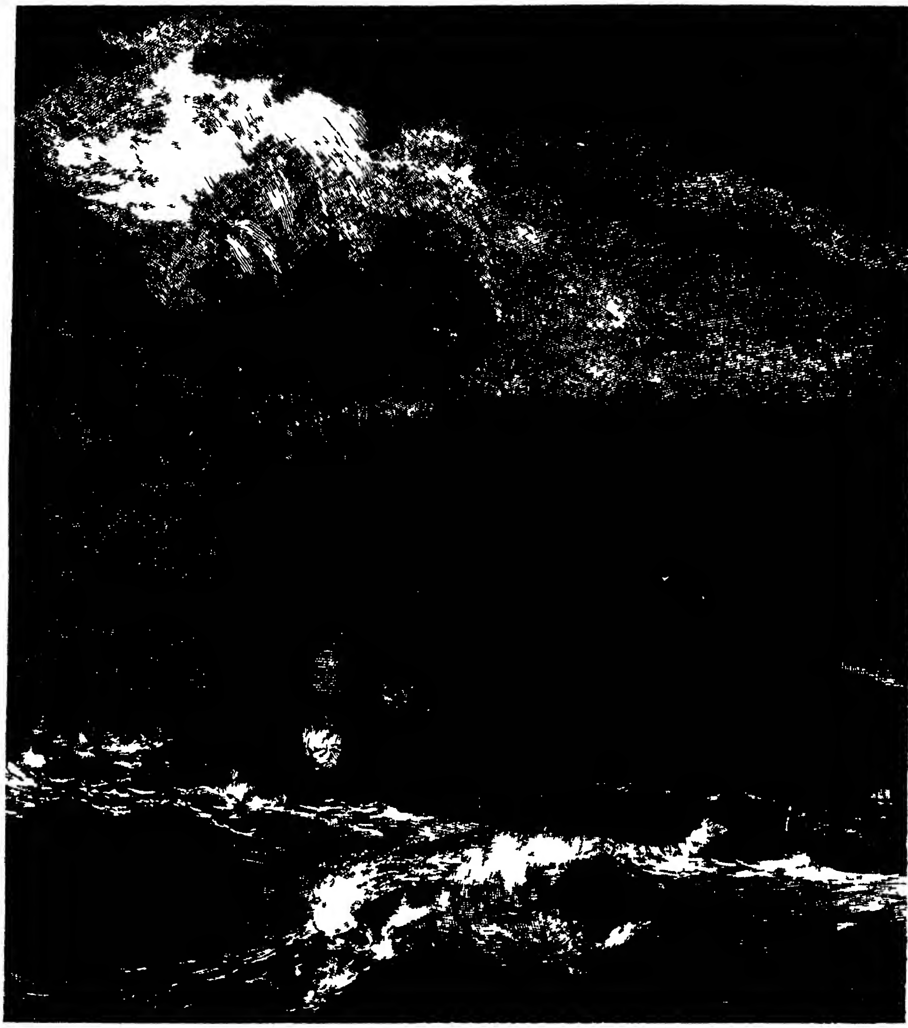
Rafe's Chasm, near Gloucester, Massachusetts.

this manner the energy which was in the wind comes in part to be given to the water, where it is manifested in the force with which the wave moves forward, and the height through which the water is swung in its up-and-down motion. Thus the energy of the winds, over a wide field of the ocean, is committed to the waves and sent against the land, where it is expended in the blows they strike. Owing to the swiftness of motion of the waves, they apply a prodigious force against the obstacles of the shore. Their velocity of movement is sometimes as much as sixty feet per second, and the pressure they apply to any fixed object they encounter exceeds six thousand pounds to the square foot of resisting surface, or perhaps one hundred times the force of a storm-wind which produces this wave-motion.

Where the wave meets a steep cliff of compact rock, at whose base the sea is deep, this pressure, though great, may have little disruptive power; but where the water is shallow, and there are fragments, which various chances have separated from the shore, lying on the bottom, it tosses these with great force against the opposing wall. Stones three feet in diameter, though weighing over a ton, are sometimes hurled against the cliff as swiftly as a strong arm can throw a pebble. The rebound due to the elasticity of the rock and the reflux of the wave rolls the stone away from the point where it strikes, so that again and again, several times a minute, with each incoming wave, the blow is repeated, until the sea becomes quiet or the stone is ground to powder. In this way every rocky escarpment whose base rests in shallow water is constantly undermined, and the overhanging fragments fall down, to be in turn used to batter the base of the cliff.

It is almost certain that the resisting power of this rocky

wall of the shore will very much vary from place to place along its line. Differences in actual hardness will favor or hinder the assault of the sea, causing the line to have the



Chasm worn through by the Sea Azores

combined salient and re-entrant angles—to borrow a term from the art of fortification—which give picturesqueness to the rock-bound shores of the ocean. On each of these small re-entrant angles the sea has more cutting-power than on the

headlands, at least until the bay extends some distance into the land; partly for the reason that in this bay the waves are somewhat heaped up by the convergence of the shores, but mainly because the fragments of rock torn from the headlands are swept into these pockets, and thus provide the waves with the armament with which they do their effective work. Imprisoned in these contracted bounds, the bowlders cannot be dragged out by the waves into deep water, and thus the supply is generally sufficient to insure a constant cutting-action as long as the waves are high.

From the apex of this re-entrant angle, where the blow of the wave-hurled stones is most effective, a cavern is apt to extend into the cliff. It is generally narrow, and thus the overlying rock is readily supported for the width of the arch. It may be driven in for a distance of some hundreds of feet before the friction of the waves on its sides exhausts their power, or the pressure of the air, which is driven before the piston of water as it rushes in, filling the whole space of the crevice, hinders the action of the blow. When these caves are excavated in rock containing many rifts, as do most of those along our American shores, the constant jarring of the waves and the action of frost are apt to tumble the roof into the space below. In this case the crevice assumes the form of a chasm, or a spouting-horn. The only really fine sea-caves which the present writer has seen along the American coast are in the Magdalen Islands of the Gulf of St. Lawrence, and the other shores of that noble sea, where relatively soft rocks, with few disorganizing rifts, are open to the assaults of the waves. In Europe, because of the much greater extent of shores of soft and tolerably massive rocks, these sea-caves are much more numerous and far more beau-

tiful than any of this country. They are particularly abundant about the Mediterranean. The reader is likely to be familiar with the famous Blue Grotto of Capri, which is an excellent type of these sea-caves, though it probably has been somewhat modified by art. A better known and much more beautiful variety of caverns occurs where columnar basalts, with the columns in a vertical position, face the sea-

The Blue Grotto, Island of Capri

waves, as at Staffa, an island on the west coast of Scotland. Here the jointing of the several columns enables the sea to rend them to advantage, while a rock of a different character serves as a covering for the cave.*

The last group of caverns which are in any way due to the work of water is the picturesque though unimportant

* It has recently been claimed that these Scotch basaltic caves were artificial works, excavated to serve as harbors at some unknown time in the past and by some unknown people. Notwithstanding the artificial look, due in the main to the masonry-like character of the columns of basalt, there is no doubt in the minds of geologists that they are the work of the waves alone.

group of grottoes known in the Alleghany Mountains as rock-houses. These interesting recesses—hardly to be termed caverns, for they never penetrate the cliffs beyond the light of day—abound in Kentucky, Virginia, and Tennessee, and are usually limited to the escarpments or outcrop-cliffs of the millstone-grit, a thick formation of sands and conglomerates which underlies the true coal-measures. The hardness of this formation varies greatly. There is often a very resisting stratum above a bed where the rock is so soft that it may be crumbled by the fingers. When this softer portion becomes wet, and then exposed to severe cold, its outer surface often becomes converted into sand, which, as soon as the frost leaves it, falls to the floor. This sand is caught up by the wind and blown away; but before it escapes from the recess it is much beaten against the soft walls, still further assisting the process of decay. In this manner the grotto is enlarged, to the point where the overhanging rock is no longer supported and falls across the front of the arch. It is common to find these recesses with an overhanging roof projecting from thirty to fifty feet beyond the innermost part of the grotto. This soft sandstone, the excavation of which forms the "rock-house," is often penetrated by interlaced harder lines, where the sand has been cemented by oxide of iron which has penetrated along the joints. When the walls have long been scoured by the wind-swept sand, these harder parts stand out from the wall, forming a singular and beautiful fret-work, resembling in its decorative effect the arabesque figures of Moorish ornamentation. The rock-house type of grotto in the Eastern United States is almost altogether limited, so far as the present writer's observations go, to the millstone-grit, though they scantily occur in some of the sandstones of

the overlying true coal-measures. But in the millstone-grit, from Pennsylvania south to Alabama, they so abound that for almost the whole distance, where the edge of this grit is exposed, there is hardly a mile where there is not a comfortable shelter from a thunder-shower, where the sheep find protection in winter storms, and the lion-spiders make their curious traps of sand. This continuous undercut cliff shows us how the topography of a country is dependent on the structure of the rocks which underlie its surface, and how the physical conditions of any one stage of the earth's history continue for all time to have a permanent influence on its aspect. The millstone-grit deposit was formed at a stage in the earth's history when great quantities of sand and pebbles were swept about by strong currents, and rapidly built into beds which differ greatly in their coherence. It generally happens that the upper layers of this formation are much harder than the lower; hence the steep and, often, overhanging wall along its outcrop.

In the Rocky Mountains this peculiar structure occurs in later stages of the geologic periods, and affords many noble grottoes of the rock-house type. In both the eastern and western districts these overhanging cliffs were more frequently used by the Indians for dwelling-places than the true caves. In Kentucky they were, apparently, in some cases the seats of a tolerably permanent settlement, as is shown by the occasional mortars, for grinding corn, which the people had excavated in the hard masses of sand-stone near the sheltering arches of rock. In the Rocky Mountains the aborigines built considerable masonry edifices in these grottoes, contriving them so that they might serve at once for dwellings and as defences against attack. Except that these holds were

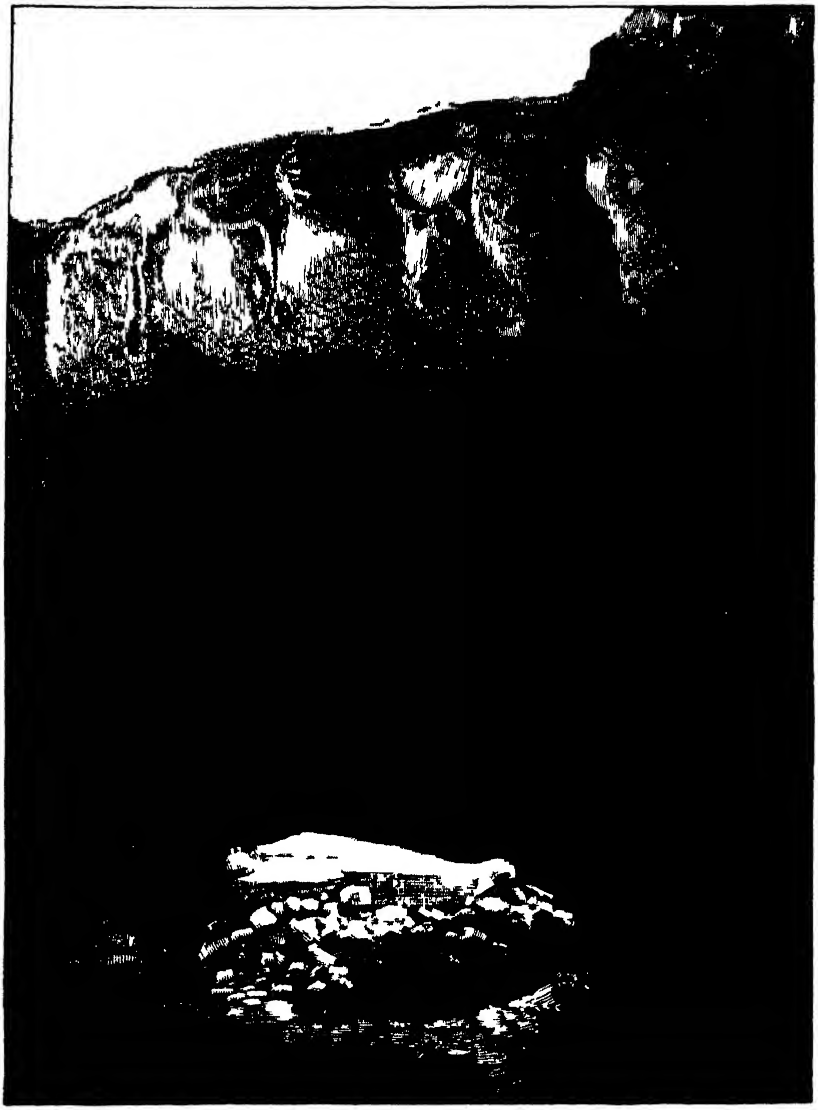
generally destitute of water, they afforded excellent places of defence, as they were assailable on but one face, and that often very easily defended.

We now have to consider the last and smallest group of caverns—those which are formed by the draining out of lava from beneath an arch or roof which the solidification of the fluid

Cave-dwellings, Nevada (Showing Rock House type of caverns.)

rock has formed. It is hardly necessary to show the reader how exceptional this group is; how it is limited to volcanic countries, and even there is of slight importance, if we measure that importance by the number and extent of the underground spaces which come into the class. Although this group of caverns is limited in number, it constitutes some of the most interesting, as well as the least known, of the sub-

terranean spaces of the earth. The commonest way in which volcanic caverns are formed is as follows: When the lava



Cave under Lava Crust Sandwich Islands (Formed by the flowing away of lava from beneath a hardened crust.)

contained in a crater remains for some time at one level, it freezes, or solidifies, as a thick sheet across the floor of the cup-shaped cavity. After it has become firm, the lower-lying

fluid rock may, as the gases which urged it upward leak out from the crevices of the solid crust, slowly subside into the depths of the earth, leaving spaces of irregular form and, often, of vast extent. If the volcano remains long dormant—some of them are quiet for thousands of years—the rain-water gathered in the crater may fill these lava-caverns. At first it is hot and charged with acids, which make it unfitted for the habitation of animals, but in time the temperature is lowered and the water purified. It sometimes happens that these great cisterns of water become the dwelling-place of fishes, as well as of more lowly organized creatures. If now the volcano resumes its activity, this water, commingled with the pulverized lava, termed ash, and containing an abundance of dead animals, may be poured over the lip of the crater, or be tossed into the air, inundating the neighborhood with a muddy torrent.

Another form of lava-caves is found outside of the crater, where the lava-streams pour down the slopes of the cone. These streams naturally flow in the deep and narrow torrent-cut valleys which so frequently seam the sides of the volcanic elevations. At first the lava may flow with considerable swiftness; but as it becomes cooler the surface curdles, like flowing pig-iron, while the mass below retains its original fluidity. This hardening of the surface progresses until the roof is strong enough to support itself; it may then happen that the lower fluid lava flows on, leaving a rude arch spanning the cavity it occupied. Buried beneath showers of volcanic dust and, perhaps, overflowed by lava, these chambers may become converted into water-reservoirs. When the water-filled caverns are penetrated by the dykes, or fissures, filled with molten rock, the water is suddenly converted into

steam. In this way such small and temporary craters as those which lie on the flanks of Mount Ætna may be formed.

Besides these larger cavities formed in lava in the ways before described, there are many smaller rifts which are caused by the shrinkage of the lava in cooling. This shrinkage often amounts to as much as one-tenth of the mass, and leads to the production of various irregular cavities.

We have now briefly considered the ways in which the empty spaces of the earth's crust are formed. We see that by several different causes numerous cavities come to exist. It must be observed that these cavities are essentially superficial; it is certain that they are limited to the mere film on the surface of the globe. The reason why all caverns must be superficial phenomena is very simple. As we descend into the earth the pressure due to the overlying matter becomes constantly greater, until at a depth of, say, twenty miles the weight of the superincumbent rock would cause every empty space, however strong its walls, to be crushed in. Even if the rocks were very rigid, still the weight would render caverns improbable at a depth of, at most, a few score miles below the crusts. The only exceptions to this rule would be where small cavities were filled with water or other fluids which could not flow out when subjected to pressure, or possibly where very much heated gases pressed, with enormous energy, against the weight of the superincumbent rock. But the vast areas of granite, marble, and other crystalline rocks which have once been buried at great depths beneath the surface show us, by their compact structure and the total absence of caverns, that deeper parts of the earth are destitute of vacant spaces.

Many speculative minds have fancied that the central portions of the earth were hollow, and in this imaginary realm have found a larger field for fancy than the real caverns afford. This notion is an old one; it had a certain currency in Germany more than two hundred years ago. In the early part of this century the speculation was renewed or, more likely, separately invented by Captain Symmes, of the United States Army. Symmes was an original genius, with a more adventurous spirit than most speculators. He not only proved to his own satisfaction the existence of this gigantic "hole," but he endowed it with a luminous atmosphere, the glare of which, shining through the entrance-ways at the poles, gave rise to the aurora borealis. In the true explorer spirit he resolved to journey to this nether realm. With eminent foresight he perceived that, when his ship turned round the sharp angle which had to be passed in proceeding from the outer to the inner sea, the sudden change of direction might snap the masts away from their fastenings. He therefore planned a strong vessel whose spars might be quickly lowered to the deck. He issued invitations to many eminent men of science to accompany him on his journey. But, with greater good-fortune than attends most dreamers, he died before setting sail.

Although we must dismiss the notion of a central space, the earth constantly contains in its more superficial parts a great number of cavities, which have an important influence on the deposition of minerals of value to man, and which afford a field for the development of a singular group of organic beings. These caverns are constantly forming and constantly being destroyed. None of the superficial, or cold-water, caves are more than two or three geological periods

old; they constantly vanish as the surface of the earth wears down to them. But those of the deeper earth, formed by the migrations of the heated waters, are among the older products of water-action; they may have kept their forms since a time when the hills which overlie them had not begun to be carved out by the superficial streams.

RIVERS AND VALLEYS.

Advantages of Beginning Study of Geology with River Action.—Description of a River Valley.—History of Rain-Drops; Mountain-Torrents; Processes of Erosion.—Passage from Torrents to Rivers.—Alluvial Terraces.—Effect of Plants on Alluvium. Effect of Tributary Streams.—Ox-bows and Moats.—Function of Alluvial Plains.—Effect of these Deposits on Conditions of Ocean; Erosion of River Channels.—Waterfalls.—Classification of Cataracts.—Niagara Falls: Effect of their Recession.—Effect of Elevation of Continents.—Base Level of Erosion.—Action of Subterranean Water.—Wanderings of Rivers.—Distribution of Streams.—Effect of Changes of Elevation of the Land on Rivers.—Effect of Mountain Systems.—Geological Consequences of Distribution of Rivers.—Comparison of Ohio with Colorado River.—Formation of *Buttes*.—Deltas: their Influence on Man; Advantages for Primitive Peoples.—Change and Destruction of River Valleys.—Dislocations; Glacial Deposits; Lava Streams.—Evidence from Old River Channels Concerning Antiquity of Men.—Effect of Forests on Rivers.—Problem of the Mississippi River.—Control of Floods.—Danger from Reservoirs in River Valleys.—Irrigation.

THE greater part of the facts with which geologists have to deal possess for the general public a recondite character. They concern things which are not within the limits of familiar experience. In treating of them, the science uses a language of its own, an *argot* as special as that of the anatomist or the metaphysician. There is, however, one branch of the subject the matter of which demands no special knowledge for its understanding, viz.: the surface of the earth. At first, geologists were little inclined to deal with the part of their field which is visited by the sun. Gradually, however, they have come to see that this outer face of the earth is not only a kindlier but a more legible part of the great stone book, and they have made a division of their work which they entitle

Surface Geology. In this division they include all that is evident to the untrained understanding, the contour of land and of sea-floor, the aspects of shores, the conditions of soil, etc. Under the head of Rivers and Valleys we propose to consider one portion of this simple but ample division of geologic science.

If the reader wishes to begin a series of studies of an unprofessional character which will lead him to some of the most important fields of knowledge which the earth's science can open to him, he cannot do better than find his way to his subject through a river-valley. There are many advantages offered to him in beginning his inquiries in this pleasant way. In the first place, the outward aspect of the phenomena with which he has to deal is already familiar to him. We can all recall to mind some of these troughs of the earth through which flows a stream, be it mountain-torrent, brook, or river. The steep or gentle slopes of the valley toward the agent which has constructed it, the flowing water, as well as many of the important actions of the stream in its times of flood or in its cataracts, are also familiar. In fact, there is not a feature or a phenomenon visible in the valley which has not a popular name, indicating that it is a matter of common and easy observation. Whoever will follow an ordinary stream from its sources to the sea in such a journey as he may make in a few days' travelling, and will avail himself of its teachings, with the aid of the simplest understandings derived from a knowledge of physical laws, will obtain a clew to a very large part of the earth's machinery.

To see the actual beginning of the river under the conditions which are best for our inquiry, we must observe the surface at some point on the dividing line between two streams

where they head together, near the crest of a mountain, in a time of rain. All that is visible are the drops of rain which slip out of the air and patter on the surface of the earth. We must be prepared at the outset to look past this simple fact of rainfall and to conceive the physical history of the drop of water since it left the surface of the earth in its journey through the clouds and back to earth again.

The story of the rain-drop before it comes to the earth is very simple. The heat from the sun, aided in a small measure by the heat from all the stars, evaporates the water from the earth's surface, mainly from the sea, and removes it in the state of vapor to a height of many thousand feet above the earth's surface. It is maintained there by the heat which it has absorbed, and thus the main spring of the rain is in the sun. After abiding awhile in the upper regions of the atmosphere, by some of the many chances which beset the clouds, the vapor is cooled; it condenses from the loss of heat, and falls as rain or snow. The circumstances of our imaginary mountain top, if that summit be at a considerable height above the sea, favor the cooling of the cloud and therefore the precipitation of this rain. These uplands retain the cold of winter, and during night they pour forth their heat by radiation through the thin air, with more rapidity than the lower lands, which are covered beneath a thicker blanket of atmosphere.

When the drop of rain falls to the earth's surface, if it be of ordinary size, it gives a sensible blow. If that surface be covered with a thin layer of scattered sand-grains or small pebbles, we may observe that the bits of rock dance about and thus apply a little of the force which comes from the drop, to rub the stone on which they lie. At first, the water

spreads over the earth's surface as a thin sheet, but as that surface is never perfectly level, it is, provided the rock be bare, quickly gathered into rivulets; or if it be covered with mosses, or the thin layer of porous soil common to mountain-tops, it may for a moment disappear from sight in the spongy mass; but a little farther down, we find that it is gathered in rivulets, which quickly join together, so that in descending even a hundred feet below the summit, in a time of rain, we find a number of shallow valleys, each occupied by a little rivulet. The union of these streams gives us one of more power, which may be taken as a typical mountain-torrent. We observe that such a stream descends with considerable rapidity; it is rare indeed that it does not have a fall of more than fifty feet to a mile. The rate of fall in steep-faced mountains often amounts to as much as five hundred feet in that distance. As soon as the stream is more than two or three feet wide and a foot in depth, we begin to see evidences of its energy. Even if the fall be but at the rate of fifty feet to the mile, we shall find that such a stream is able to urge forward with great violence masses of stone several inches in diameter. If we roll a stone the size of a man's head into the channel, it is swept along, bumping violently against the obstacles it encounters, striking first one rock-bank and then another, until it becomes fixed in some crevice. If, after the pebble has journeyed for a few hundred feet, we recover it from the stream, it is often easy to note the dents on its surface, produced by the collisions on its journey. In most cases there has been a corresponding blow and an equal wearing inflicted on the firm rocks against which it collided.

A little observation with streams having different rates of fall will show the observer that the ease with which a stone

is urged onward, and the size of those which a stream of given volume can carry, depend in a remarkable way on the rate of its descent toward the sea level, and therefore on the velocity with which its waters flow. Computation and experience have shown that this increase in speed is proportionate at least to the cube, or third power, of the velocity with which the current flows. One distinguished student of this hydrau-

Torrent Bed in Eastern Kentucky

(Showing channel embarrassed by masses of stone fallen from the sides of the valley)

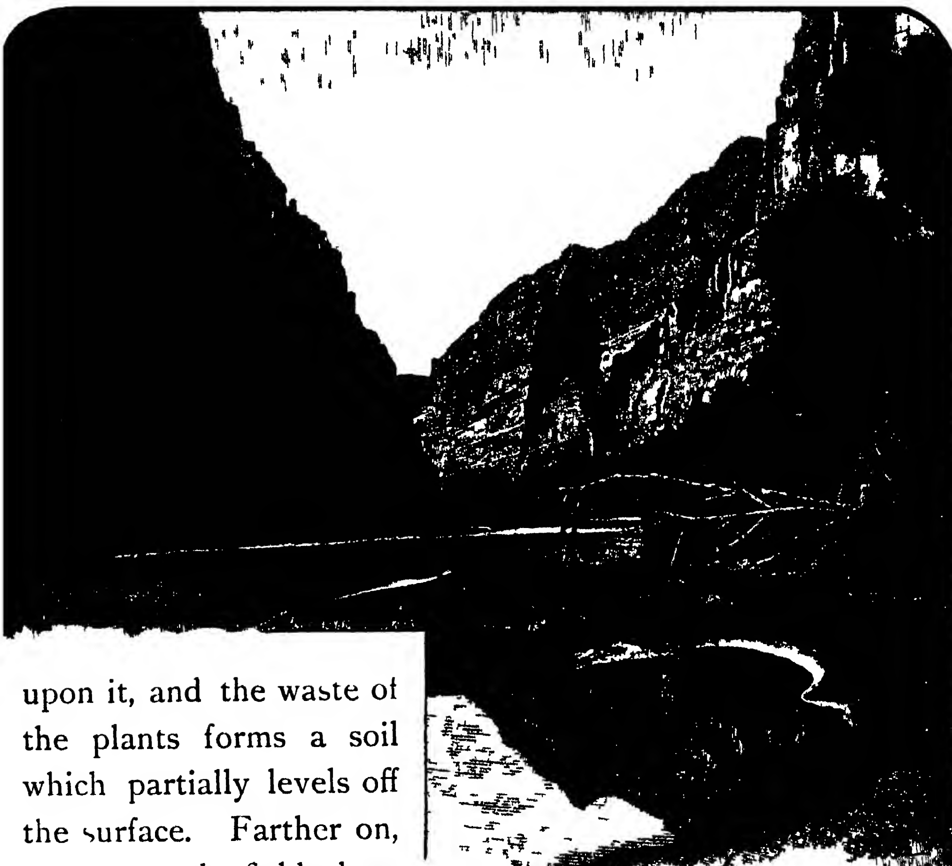
lic problem has come to the conclusion that the increase of the propulsive power of the stream upon the fragments which it encounters is as the sixth power of its speed. It is not worth while for us to pause in our imaginary journey to consider whether the third power or the sixth be the rate at which the efficiency in the carrying power of the stream increases with its speedier flow. It is enough for us to know that the water, with very slight increase in its velocity, is

able to carry a very much larger stone than it could before its speed was increased.

The sides of these mountain-torrents are generally steep. It is rare indeed that the slopes which lead to them are much less inclined than the roofs of ordinary houses. Over all the surface on either side of the torrent, frost and other agents of decay are constantly at work breaking out bits of stone or forming soil. This mass of broken-up rock is constantly slipping down the sides of the valley. Every time the winter frost seizes it, it expands a little, and is thus shoved downward; frequently, when soaked with water, great sheets of it slip swiftly, as mud-avalanches, into the stream. In this way the torrent is always provided with fragments which it may grind up into pebbles, sand, and mud, and bear onward to the fields below. In times of drought, these stream-beds are occupied by rivulets of clear water, and at such periods the observer gains no idea of the vigor with which the mill works; but in times of heavy rain he will find the water turbid with sediment made by the attrition of pebbles against the bordering walls of the stream and upon each other. He then sees whence come the sediments which are so important a feature in the lower portions of the river-system. From any commanding elevation in a mountain district, we may see scores or hundreds of those torrent-beds within one field of view. In periods of heavy rain, the roar arising from the moving stones is often a very striking feature.

Descending the channel of any of these mountain torrents, we find that after a few miles of course, though the brook steadily gains in volume by the contributions of tributary streams, it gradually diminishes the swiftness of its descent. At a certain point it ceases to bear onward all of the larger

stones which come into its possession. These fragments gather upon the banks, forming a rude terrace. Still farther down, where the slope is less considerable, the smaller pebbles are left behind, crowded into the interstices of the larger fragments. The terrace becomes more distinct, vegetation gathers



Valley Showing the Beginning of New Terraces just below the Torrential Portion of the Stream

upon it, and the waste of the plants forms a soil which partially levels off the surface. Farther on, we come to the field where the annual overflow of the stream during the spring floods heaps a quantity of the sand and mud upon this foundation of coarser material; we then have the beginning of the alluvial terrace. At first this alluvial terrace is but a narrow belt on either side of the stream, which, swollen by its

flood-waters, often breaks new channels through this bench of detrital matter. In fact, all this marginal accumulation is of temporary duration, for the stream is as yet wild, and in its annual floods is apt to undo the construction-work of the previous years.

When the stream comes to have a distinct and somewhat enduring alluvial belt on either side of its path, it has entered on the stage of a river. It is indeed on the presence of this marginal accumulation that we most rest the distinction between a torrent and a river. From the place where the terraces begin to form, downward to the mouth of the stream, the conditions of its flow are vastly affected by its reactions upon this detrital matter. In most cases, with each mile of its descent the magnitude of these deposits increases. The alluvial lands stretch farther and farther on either side; the materials which compose them grow finer and finer as we descend in the valley, for the reason that with this descent the slope of the stream in most cases steadfastly diminishes and its ability to urge forward coarse sediments decreases in a rapid ratio.

The alluvial deposits which border our rivers owe their existence to the fact that the torrential head-waters, by their great velocity, bear forward, beyond the mountain districts, a large amount of materials which are of such a coarse nature that the larger but less powerful lower part of the stream cannot urge them onward to the sea. In all its journey to the ocean, the river is continually struggling with this detritus. It deals with this burden in the following manner: The motion of the stream is swiftest in its central parts, because, in most cases, the water is deepest in that part of its bed, and is therefore the least influenced by friction. On the

sides of the stream where the water is shoal, the current is least swift; therefore in these marginal parts it constantly tends to lay down sediments. As soon as the alluvial terrace is formed, certain kinds of trees, particularly our willows and aspens, find a lodgement upon it. They push their roots out into the nutritious mud and enmesh it in their net-work of

Border of Alluvial Terrace on Green River, Ky

(Showing the manner in which the forest occupies and protects the lower terrace of the valley.)

fibres; they also send up from these roots a thick hedge of stems, in which the flood-waters lose their swiftness of motion and therefore drop their contained sediments. In the state of nature, all our American streams, and those of most other countries as well, are bordered by a close array of these plants, all of which are at work to win against the channel of the stream. But for the cutting power of the stream, they would quickly close its channel; as it is, they constantly crowd its waters within a narrow pathway.

Against the encroachments of the alluvial banks brought about by the action of the water-loving trees, the river prevails by fits and starts, under the action of a curious law which causes its current to rebound from bank to bank. The nature of this principle of rebounding can best be seen by observing the effect arising where a jetty is built at any point in the course of one of our larger rivers. The jetty causes the water to sweep away from its obstruction and to strike against the opposite shore. The crowding against the shore gives its current increased power; it will wrest away the alluvium from the grasp of the roots, and will then cut under the trees, causing considerable areas of forests to be precipitated into the waters and borne away to the sea. From the point of impact, the current will again rebound in a manner which will cause it, at a certain distance below, to strike against the opposite bank, where it will again make swift encroachment against the forest-protection. After this second assault, it will swing across to a lower point on the shore against which it first impinged, and so the oscillations from side to side will be propagated down stream, it may be for a hundred miles or more. A single jetty of this description, as it has been observed in the rivers of India, will affect the oscillations of the current for an indefinite distance downward in its course. That which is accomplished by artifice in an immediate manner is more slowly brought about by natural causes. Each tributary stream which enters the main channel commonly has a greater swiftness of current than the larger stream into which it flows. It therefore bears in a mass of pebbles and builds a natural jetty or bar at its mouth, thus gradually forcing the current of the larger stream against the opposite side, creating a bar there. It is furthermore to be noted, as is

shown in the diagram (p. 154), that between the points where the river impinges against the bank there is a space of dead water or eddying currents in which the forests find it easy to make head against the river and to extend the alluvial plain.

Cumberland River Ky from Taylor s Hill

(Showing the relation of alluvial plains on upper portion of the river to the hills which form the valley, also the beginning of the true river-curves formed by the struggle of the stream with its sediments' Photo by Ky Geol Survey

Thus, in the process of nature, it comes about that our rivers tend to build channels in their alluvial plains which are extremely devious in their course. If the alluvial plains be wide, the river is constantly forming great ox-bow-like curves, isthmuses with narrow peninsulas such as are often seen in the lower portions of the Mississippi valley. Finally the narrow places which connected these promontories on the shore are cut through in some time of flood, the river finding a shorter way downward to the sea, leaving its former circuit as a great

pool, or moat, as it is called by the common folk along the banks of the Connecticut River.* It often happens in the lower Mississippi that the course of the river around the promontory of the ox-bow is ten or more miles in length, while the space across the neck is less than a mile in distance. When the river finally breaks across the neck, the whole system of rebounds of its current against the banks, from the point of change downward to the mouth, may become altered. The points which before were in process of erosion may become

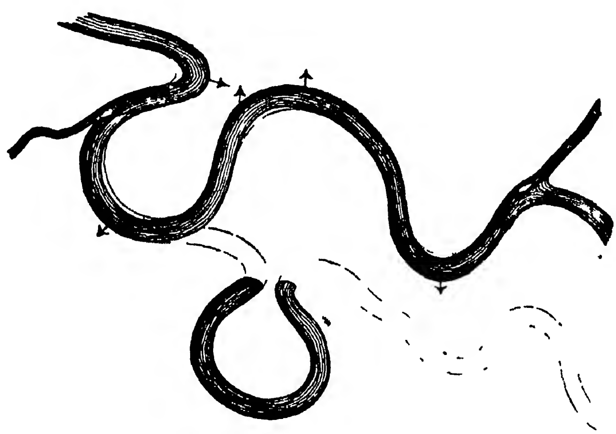


Diagram Showing the Wanderings of a Stream in an Alluvial Plain

(The arrows on the sides of the stream indicate the direction of its movement; the horseshoe-shaped pool is an "ox-bow" or "moat")

the seats of deposition, and those which previously were gaining may begin to wear away. In this manner a river, in time, wanders to and fro across its whole valley, taking material

* This term "moat" deserves a place in our geological language, for the reason that it is a brief and expressive word for the topographic feature, ill-described in our present system of naming. Moreover, it preserves, in an interesting way, a memory of mediæval conditions. The name was doubtless given because of the likeness which the early settlers saw between these circular ditch-like pools and the defences which, in the seventeenth century, were still familiar objects about many of the country houses in Great Britain. I shall therefore use the term in the present writing and hereafter in the sense above indicated.

from one side, sorting it over, removing that part which is fine enough to be borne away by the current, and rebuilding the remainder into the alluvial plains.

We are now prepared to consider a very peculiar and most important function which these alluvial plains perform in the physical life of the earth. In such a valley as the Mississippi, we have probably not less than fifty thousand square miles of alluvial plains which have been formed of the waste removed from the rocks in the torrential portions of the streams in the mountain and hill districts of the valley. This alluvial material is, on the average, not less than fifty feet thick. It is therefore equivalent to about five hundred cubic miles of matter. Now, this great river carries out to sea about one-twentieth of a cubic mile of sediment each year. This sediment which goes into the sea is in small part directly derived from the action of the mountain-torrents; in larger part, it is composed of waste taken from the alluvial plains by the wanderings of the various streams which constitute the Mississippi system of waters. It therefore follows that the average time required for the sediment discharged from the mouth of the Mississippi to make its way from the head-waters to the sea is not less than ten thousand years. As soon as a pebble or other bit of rock is laid away in the alluvial terrace, it begins to decay; the vegetable acids which penetrate the mass in which it finds lodgement favor its disintegration. When it is turned over by the stream at the time of encroachment on its resting-place, it probably falls to pieces, the finer bits are hurried onward by the stream, those too coarse for the current to control are again stored away in the bank to await further decay. In this manner the alluvial material lying on either side of rivers is a great storehouse, or rather we should say

laboratory, in which sediments are divided and brought into a chemical condition which permits them to be taken into the control of the waters and borne away to the ocean, in order to become rebuilt into strata, which are in time, with the growth of the continents, to become dry land and be again subjected to this erosive work. Were it not for this system of alluvial storage and decay, the seas could not be supplied with the *débris* essential for the maintenance of the life which they contain; for that life, unlike the life of the land, does not depend on the soil of the ocean floors, but upon the dissolved matter contained in the water, from which the marine animals and plants take all their store of nutrition. This nutrition comes mainly from the land-waste brought to the sea in the state of solution by the streams, and, as we have just seen, the comminution and solution of this waste depend upon the work which goes on in the laboratories of the alluvial plains.

It is true that a portion of the mineral matter contributed by the land to the sea comes from the seashore, and yet another portion from volcanic ejections which are poured out from the numerous vents of oceanic islands. The material taken from the seashore into solution by the sea water is, however, small in quantity, and this for the reason that the ocean water has usually but a small amount of free carbonic acid to aid in its solvent work. The material contributed from volcanoes is larger in quantity than that won by the ocean waves from the coast line. A large part of this volcanic waste is, however, borne to the ocean from the land on which it falls, by the streams, which, as explained in the chapter on Volcanoes, readily remove the incoherent volcanic waste by the action of their waters, and bear it to the sea.

We have now seen the way in which the water operates upon the surface of the stream-beds. At the source of the mountain-torrents, a pound of water has in it, by virtue of its height above the level of the sea, a great store of energy, which it may apply to the erosion of the earth's surface. Let us suppose that when it comes to the earth it is three thousand feet above the ocean's level. It has then as much force

Showing Alluvial Terraces of Soft Material Rapidly Eroded by a River which is Constructing what in Time will be a yet Lower Terrace

to expend as would be required to lift it to that height above the sea. At first the stream plays the part of spendthrift with this energy; the greater portion of the force is expended in brawling with the stones and in beating against the limits which confine it. In the first five miles or so of its path to the sea it uses up in its descent perhaps one-third of its

dynamic resources, and so, for the last thousand miles, it may not have more power at its command than it gave out in the first five miles of its journey.

Thus our streams, though always growing larger, are continually becoming less and less powerful in proportion to the weight of water which flows over their beds. In the lower portion of their courses they have very little capacity for eroding the rocks over which they flow, except where that power is due to some peculiar circumstances. They deepen their beds slowly, and the greater portion of this deepening is accomplished by the corrosion or chemical decay of the rocks over which they flow. Still, certain peculiar circumstances may give them a chance to cut down the floors of their lower channels. This work is done in either of the following ways: When the lateral swinging of the river-beds to and fro through the alluvial plain dislodges great forest-trees from the bank, these trees often have great quantities of stones entangled in their roots. These roots are thus held against the bottom while the trees are swept onward by the current, and so the entangled stones rasp upon the bed and serve to wear the channel deeper. Again, it often happens in cold countries that the rivers are deeply frozen, and during the winter season, in the shallow water, the loosened stones of the bottom may be entangled in the ice. When the time of "breaking up" comes, the sheets of ice, as they float downward in great fields, strike against the banks of the river where there is a sharp bend in the channel, and, owing to their great momentum, are heaped up in a wall of fragments, which may in a few minutes dam the river quite across. Owing to the pressure to which these cakes of ice are subjected, they freeze together, and the whole of one of these ice dams

Stream Bed with Bowlders Formed from Angular Masses Rolled in Times of Flood

or gorges becomes a solid mass. When this happens, as is easily conceived, the stream rises rapidly, forming a great lake above the dam, while it drains away below, and thus, as in the Ohio River, these dams may have a difference of twenty or thirty feet of water above and below their obstructions. In a brief time the pressure of the water above the dam pushes the whole mass forward, grinding it upon the bottom and the sides, and so powerfully eroding the rock-bed in which the stream flows.

As long as the river flows onward over rocks of uniform hardness, especially where the strata lie in horizontal attitudes, the course of the stream generally exhibits a uniform descent. Various accidents in the attitude of the rocks may, however, give rise to rapids or waterfalls. These features in the course of a river are so important in its mechanism, especially with reference to the interests of man, that they deserve a careful consideration, which we shall now give to them.

Waterfalls and rapids owe their existence in the main to one of three conditions of the bed-rock. These conditions are as follows: First, the path of the stream may be crossed by a dike or a vein, which are rifts in the rocks, filled with some deposit brought into them by the action of water or forced to its place in the condition of a lava. Where these dike- or vein-materials are softer than the neighboring rock over which the stream flows, the river easily cuts them down and they create no interruption to its course. Where, however, as is often the case, the rocks which fill the fissures are harder than the materials which formed its walls, the river is obstructed, and we generally have a cataract, that is, an irregular fall, in which the stream takes no one conspicuous plunge. Another case in which a local hardening of the

stream-bed produces a waterfall is where a stream, flowing over rocks which may be horizontal in their attitude, encounters a coral reef, formed on the old sea-floors in which the strata were deposited. In this case the crowding together of the fossil corals may make the rock much firmer than the neighboring portions of the strata, and so produce a decided interruption in the uniform descent of the stream. Only one important case of reef-cataract is known to me,—that which occurs in the Ohio at Louisville, where coral-reef in the Devonian period has so far interrupted a gentle descent of the river as to create a formidable obstruction, only passable, save during the flood-times of the river, by means of a canal extending from the head to the base of the rapid. The most common condition which leads to the formation of a waterfall, the condition which gives us the greater part of the fine falls of the world, is where a river flows across strata which dip or sink downward in the earth toward the head-waters of the stream. In this condition, wherever a hard bed of the strata overlies a soft deposit, the stream inevitably forms a waterfall.

The first two of the above-named classes of waterfalls demand no very extensive consideration. Those produced by dikes and veins are generally conspicuous only in the torrential portion of a river-system. The veins and dikes account for a very large part of the little cataracts which diversify our mountain-torrents. Coral-reefs are so rare in our older rocks that they are seldom cut by the streams, and are therefore not often seen, even by the professional student of geology. The third group, in which each plunge of the fall is due to the upstream slope of strata, alone demands some special consideration.

Falls due to inclined strata can best be represented by Niagara, perhaps the noblest of all such geological accidents. As is shown in the diagram, we have at Niagara Falls a tolerably hard layer of limestone, belonging to a division of the Silurian age, which has indirectly received its name from this great cataract. This Niagara limestone is underlaid by a considerable thickness of softer shaly rocks known as the Clinton group. The waters of the Niagara River plunge over the hard rim afforded by the limestone and descend about a hundred and seventy feet, acquiring in this movement a very great velocity. At the base of the fall, the water strikes against a mass of hard fragments which in succession have tumbled down from the resisting upper layer. These fragments, set violently in motion, cut out the soft material, the erosion of which is also aided by the violent whirls of water and of spray driven against the shaly beds in the space behind the fall. From this wearing action, the soft materials are constantly working backward more rapidly than the hard upper layer is worn away, and so, from time to time, the projecting shelf over-the waterfall is deprived of support and tumbles to the base in fragments, which, in turn, are used for the further erosion of the soft deposits. In Niagara, as in all other waterfalls of this description, the border of rock over which the plunge takes place is constantly and pretty rapidly working up stream. The fall is progressively decreasing in height, as is shown in the figure; and in the end, when the hard layer has descended to the general level of the stream-bed, especially when the softened limestone rocks have passed altogether below that level, the fall will disappear—first passing into the stage of a cataract, and afterward vanishing altogether.

In the case of Niagara Falls the rate of retreat is about three feet in a century. This rate is very variable. It was probably more rapid in the past than at present, for the reason that the undercutting power of the falling water diminishes with the decrease in the height of the precipice over which it plunges, and this height has been growing less and less ever since the fall began to be. Although the retreat of

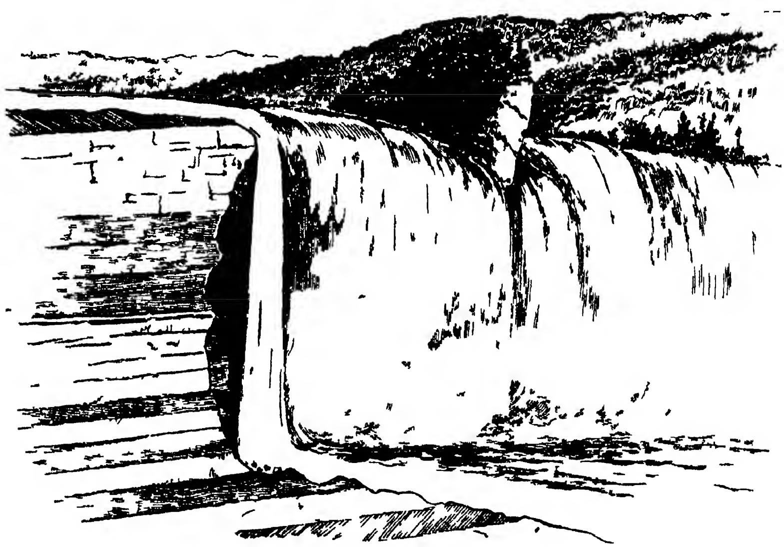


Diagram of Waterfall of Niagara Type

(Observe the effect of hard limestone in determining the position of the top of the fall. Note that as this is worn away the vertical plunge will be diminished.)

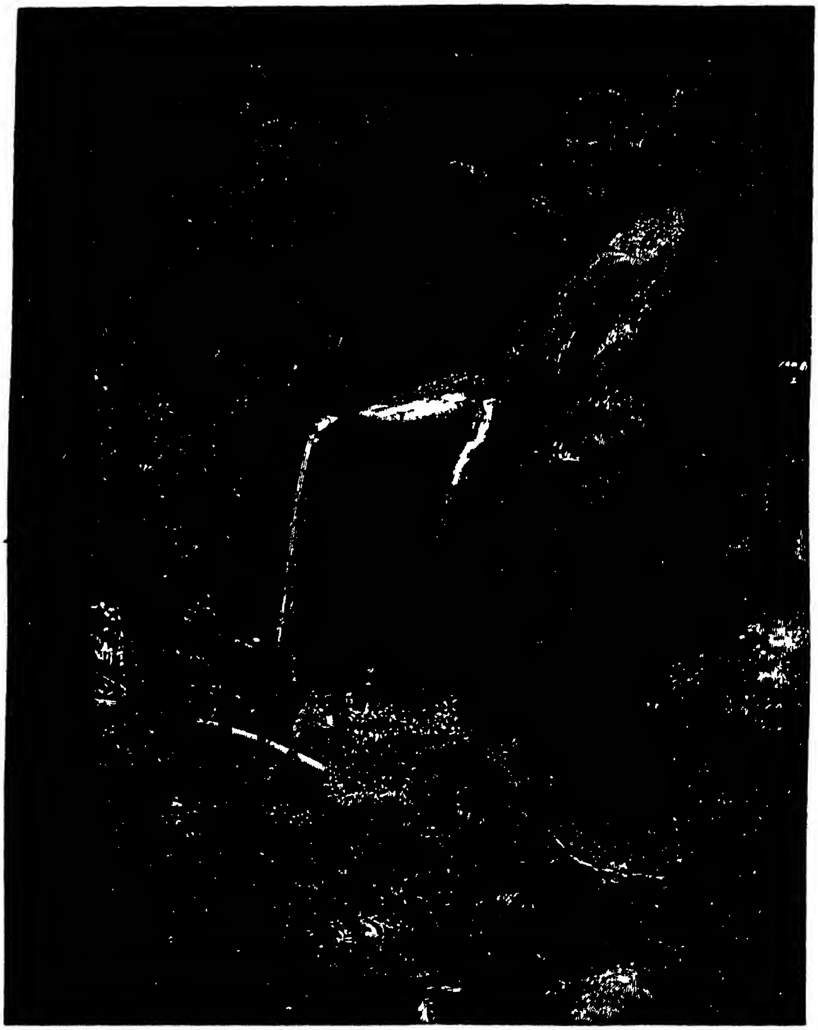
the fall is slow, it will in a very brief time, in the geological sense of that word, lead to certain momentous consequences. When the hard layer of Niagara limestone passes below the bed of the river, the stream will then cut upon rocks of another constitution, making for a time certain small falls at a higher geological level; but in the course of ages, much less long than those which have elapsed since the birth of this waterfall, the gorge of the river will extend up into the basin of Lake Erie, draining away a considerable portion of that

fresh-water sea. We shall then, if the continent retains its present height above the level of the sea, have another system of cataracts, in the passage between Lake Erie and Lake Huron, which will also in time be worn away. Other cataracts will then form at the exit of Lake Michigan; and thus the lower lakes of our great American system would be diminished in area, or perhaps even disappear. At a yet later stage, we may look for diminution in the size of Lake Superior, though that basin, owing to the strong wall which separates it from the lower lakes, is destined to endure long after the last-named basins have been diminished or entirely drained away.

From these considerations we perceive how important the movement of waterfalls may be in determining the water level of extensive areas. Not only may their retreat lead to the drainage of extensive inland seas, but as they move up stream, the drainage of all the tributary rivers, the mouths of which are in turn passed by, have their systems of flow changed in an important manner. Thus, when Lake Erie is drained away, a number of subordinate waterfalls will be developed along the streams which now empty into that basin. Each of these in turn will take up its march toward the head-waters of the river in which it forms; and so the effect of the retreat of one great waterfall may be propagated over the whole surface of the land which is drained by a great stream.

The effect of a retreating waterfall deserves to be considered with some attention, for the reason that it will afford the student the means of understanding how far the structure of the rocks in a country may influence the erosion which water brings to its surface. Each of these hard layers of rocks, as well as the other classes of dams which create waterfalls,

tends, by determining the rate of flow of the streams, to fix the rate of erosion in all parts of the river-basin above the point where they occur. Whenever such obstructions are cut



Cascada de la Sirena, near La Guayra Venezuela

(Showing stream divided by following joint planes)

away, they increase the rate of fall in the waters above them; and so this may greatly enhance the rate of down-wearing of the surface. The erosive action of the water which passes

out of a river is determined by the height through which this water descends in every part of its course. Whatever tends to increase the speed of fall in the particular portion of the basin serves to magnify the erosive work in that region. Thus, when a fall disappears, the energy which was ineffectively applied at the base of its cliff may become distributed over a wide surface in the upper portion of the valley in which it lay.

So, too, in a larger way, as the continents sink down into or rise above the level of the sea, in their ceaseless oscillations, each movement is attended by a great variation in the energy with which the streams act upon their surface. If our continent should rise a hundred feet in its southern parts, the Mississippi River would immediately begin to flow with greater swiftness, and so too all the streams which are tributary to it would have their energy enhanced up to the foot of their mountain-torrents. On the other hand, if the continent sank down a hundred feet, all these streams would at once become less effective agents of erosion and transportation. We thus see that all the erosive work of the land is to a greater or less extent determined by what is called the principle of base level of erosion. This principle, first distinctly suggested by J. W. Powell, has been amplified by other American geologists and has served to bring into clear light the peculiar sensitiveness of our streams to the position of the sea or of hard layers in the rocks which control the inclination of their stream-beds.

We must now turn our attention to another mode in which water wears away the valleys of streams. So far, we have considered only that portion of the rain which flows over the surface of the ground, but it needs only a moment's notice to

show us that this is only one element of the rainfall. If we watch any ordinary soil-covered portion of the earth's surface in a time of rain, we observe that a considerable portion of the water, an amount which varies with the amount of water which falls in a given time and the porosity of the surface, enters into the ground. This subterranean or soil water passes for a great distance beneath the surface of the earth. In this journey, the underground water plays a very different part from that performed by the superficial streams. Except in the rare cases where it forms distinct caverns, it slowly creeps on its way downward to the sea, never attaining a speed of motion which gives it any cutting power whatsoever; but in this underground journey it becomes in most cases charged with carbonic-acid gas and is thus enabled to dissolve more or less of the rocks through which it passes. Finally this underground water emerges into the open air and journeys through the streams to the sea, conveying much dissolved matter taken from the rocks through which it passes. Through the action of this underground water, all the rocks for a considerable depth below the surface are constantly diminishing in volume, tiny crevices are formed between their grains, and the weight of the superincumbent matter in most cases causes the strata to press these crevices together almost as fast as they are formed. This action is particularly conspicuous near the surface of the ground, within the limits of a few score feet in depth. The result is that in every river-valley we have the whole area gradually down-sinking by subterranean erosion. A portion of this matter, broken up by the action of penetrating water, remains as the soil-covering, but the interstitial decay and the removal of the matter go on for great depths beneath the soil. So hidden is this process that even those

well trained in such observations may not note its effects, but careful inquiry exhibits some very conspicuous results of its operation. In the Southern States of this country, it is often possible to observe a layer of limestone, say five feet in thickness, which at one point has, by some impervious overlying deposit, been protected from the action of penetrating waters. A few hundred feet away we may find the same bed exposed to this percolating erosion of water. At such points we ob-

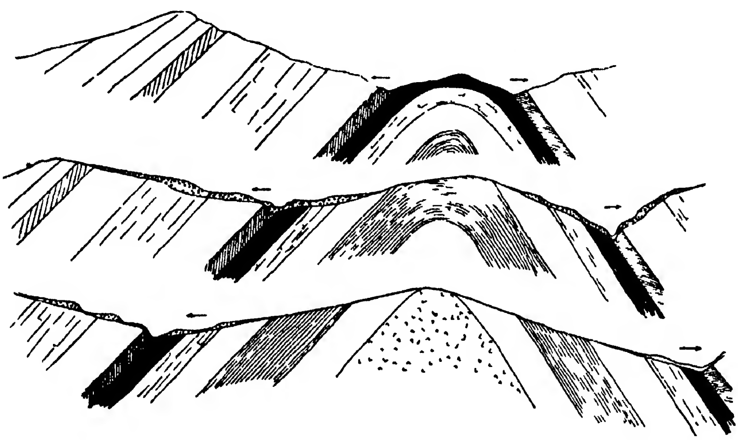


Diagram Showing the Successive Stages of Erosion in a Valley Underlaid by Tilted Rocks of Varying Hardness

(Note how the streams, at first near each other, are separated as they wear downward.)

serve that the limy matter has been to a great extent removed from the layer of rock, leaving only the clay or sand which may have been commingled with it. In this case, the layer will always be greatly diminished in thickness; what was originally a bed five feet thick may become a layer not more than one foot in depth, though the bed may in other respects retain its original form.

We observe that this interstitial erosion of rocks goes on in a greater or less measure over all parts of the river-valley. Thus, while a stream-bed is exposed to the actual cutting which the superficial portions of the river may bring about,

all portions of its valley are wearing down by the interstitial decay. It will be observed in the cut on page 167, which shows a section crossing a river-valley, that we have in such a basin two distinct topographic features. There is a channel, which, as we readily see, was carved by the flowing stream. On either side, leading up to the divide which separates the river from the next stream, is a more or less gentle slope across a wide field of country. In the main, the downward wearing of this side slope is accomplished by the percolating waters in the manner before noted. To conceive the formation of a river-valley, the observer must in his imagination combine the action of these erosive agents working on the surface and in the under earth. He must imagine an ordinary river to consist not only of the main channel, but of many tributary streams branching like the limbs of a great fan-shaped tree. Each of these branches is slowly swinging to and fro, driven about by the wrestle with its alluvial material. In time, every portion of the valley is crossed again and again by the bed of some stream in its serpentine swings to the right and left of its present path.

It will be well for the student, when standing in some river-valley of normal structure, such as that of the Ohio, or in other river-valleys south of the glacial belt, to imagine a vertical line extending from the present surface to the height of a mile above that level. He should then try to picture to himself the endless wandering of the streams in their conflict with the detritus which encumbers their beds. He must conceive that the brooks or rivers which are nearest the vertical line have again and again swung to and fro across its path. If he could restore to the surface, layer by layer, every part of material which had been taken away, and bring to their an-

cient positions all the several stream-beds, he would find his line again and again intersected by them. The time in which the stream-beds lay over the given vertical would be but brief. Perhaps, if it were possible to make an actual diagram of their position and duration, with reference to the given vertical line, we should find that not more than one-fiftieth of its space was occupied by the channels of the old brooks or rivers. All the intermediate space not so occupied by the channels indicates the interstitial erosion effected by underground water.

The distribution of rivers upon the surface of the earth depends upon a variety of circumstances, of which the more important are the amount of rainfall and the attitude of the mountain-built rocks of the country on the surface of the continent or other lands occupied by the stream. In general rivers originate in the mountainous sections of the lands and flow thence down the slopes of the table-lands which surround the mountains to the sea. The size of a river as well as the direction of its flow depend in a measure upon the existence of table-land districts and the inclination which they have. The greater rivers, such as the Amazon and the Mississippi, are found where two or more sets of table-lands slope together to the central parts of the continental area. In these conditions streams from each mountain district coalesce and form a great river. Generally the principal stream, as for instance the main Mississippi, lies at no great height above the sea-level. Thus, in the uprising and downsinkings of the continent, which in the course of geological ages are frequent, the main stream is sometimes during the periods of depression an arm of the sea, and again in times of elevation becomes a river, while the higher lying tributaries are more rarely if ever suf-

fused by the ocean waters. The Mississippi River has probably at several times thus been destroyed, the tributaries from the sea and west discharging into a great arm of the Mexican gulf, formed during the subsidence of the continent. Hence it comes about that the upper waters of such a river system commonly flow in deep gorges which they have been carving for many geological periods, while the channel of the main stream frequently covered by ocean waters flows in an indistinct and recently carved depression.

The peculiar distribution of mountains and their accompanying table-lands about the several oceans causes the amount of river waters contributed to these areas to vary in a remarkable manner; thus the continents about the Atlantic have their highlands so disposed that their waters drain towards that ocean. At least nine-tenths of the river water from North and South America, the larger part of that from Africa, and the whole of that from Europe pour into the Atlantic basin or into the seas, the Arctic or Mediterranean system, which directly communicate with the Atlantic. It is probable that more than one-half the rain-water which flows from the land escapes into this relatively small division of the oceanic areas. The Indian Ocean receives the water from several great streams in southern Asia and some of lesser importance which flow from Africa, but its share of oceanic land waters is very much less considerable than that of the Atlantic. The only very large streams which find immediate access to the Pacific waters are those of eastern Asia. From America only three considerable streams pour into the Pacific, viz., the Yukon, the Columbia, and the Colorado, none of which are to be ranked with the greater rivers of the world.

There are certain important geological consequences de-

pendent upon this peculiar arrangement of the rivers. The undissolved sediment borne out by the streams in the form of visible mud, owing to the influence of gravity upon the particles of rock material, quickly finds its way to the bottom. Hence, it arises that the Atlantic basin is the seat of a very much more extensive sedimentary deposit than the other parts of the oceanic areas. It is only the perfectly dissolved material, that which does not appear to the eye, which can journey far in currents of the sea. It is to these marine currents we owe the incessant transfer of the dissolved mineral material poured into the Atlantic, to the other great ocean realms.

Diagram Showing Gravel Terraces each Marking a Stage of Downcutting by a River
(The dotted part of the section shows alluvial material, the straight lines the bed rock.)

In order to aid the reader in forming a conception as to the history of a river-valley, a cut is given which shows in a diagrammatic way the process by which a river-valley wears downward. On the basis of fact presented in this figure, it will be well for the observer, by the use of his constructive imagination, to frame a picture of the past history of any considerable system of land waters. If this image is well brought to mind, he will have attained one of the greatest conceptions which geology offers to its votaries.

The foregoing considerations will enable the reader, in a general way, to conceive the laws under which a river-system

is developed and maintained. It is necessary, however, in order to complete the picture, to set before him certain accidents which may happen in the history of a stream. In the case of a river-basin such as that of the Ohio, a basin which we frequently take for illustration for the reason that it is one of the most normal of all those on the American continent, the natural history of the stream is as follows: When the land which now constitutes this great valley first came above the ocean, it was a region of great plains, on which flourished the dense swamps of the Carboniferous era. Through this plain, the streams seem for a time to have wandered deviously, with undetermined channels. Gradually, as the Appalachian and other mountains developed, and the slopes of the streams increased, they carved themselves channels, — the general course of these channels being determined to a certain extent by the inclination of the rocks. As the Alleghanies rose higher and the table-lands on their banks came to a greater elevation above the sea, the organization of the main river and its tributaries was made more and more complete. If the continent should continue for some geological periods without any change in the level of the sea, the mountain brooks would gradually carve down the hills in which they lie, the table-lands would slowly disappear, and the surface would return to its primeval state of a great swamp. The rocks beneath this swamp would be subjected only to interstitial or corrosive decay, for the reason that the streams would not have fall enough to work upon their beds by mechanical erosion. In proportion as the lands of the valley were high above the sea, the erosive effect of their waters would have great effect. With every foot of diminished height above the ocean-level, the energy of erosion would decrease, while the corrosive,

or underground, wearing would remain more nearly steadfast.

It is, from the foregoing considerations, easy to see that the ratio between the erosion and corrosion effected by the rainfall in a river-basin determines, in a very important way, the aspect of that region. Whereas, in the Ohio, the total descent of the waters in their great distance of flow is relatively small, corrosion may nearly overtake the erosive downwearing, and so the general level of the country will be brought down almost to the river-channel, the main stream being bordered by a line of low escarpments on the margin of its alluvial plains.

For a contrast with the conditions presented by the Ohio, where the rainfall throughout the valley is great, where the elevation of the region is slowly brought about, and therefore the corrosion relatively considerable, let us turn to the case of the lower Colorado, where the stream flows, for some hundreds of miles, through a country which has a very small supply of rain and where it receives very trifling tributaries and where the surface of the country has risen rapidly from the sea. The head-waters of the Colorado in the Rocky Mountains are fed by the considerable snowfall of that region; these melting snows maintain a powerful current through the channel of the stream at all seasons of the year. The result is, that, while the region on either side of the Colorado has been rapidly elevated during the last geological periods, there has been no proportionate corrosion of the rocks on either side of that stream. The bordering lands have remained for many geological ages little affected by underground water or the to and fro swingings of the lesser streams. The consequences of this peculiar position is that the Colorado flows

through a great cañon, which, in places, has the depth of a mile.

Between the conditions of the Colorado cañon and those of a valley such as the southern part of the Ohio basin exhibits, we have every degree of divergence of aspect, and the slope of the drainage basin toward the gorge of the stream indicates in a general way the relative intensity of the erosive and corrosive forces. There is a peculiar effect arising from the diverse hardness of horizontal strata in a river-valley, which deserves note in this part of our inquiry. Wherever it has a very hard bed underlaid by softer strata, this hard bed at first makes a precipice next the bank of the stream. If the underlying bed be so little resisting that the weather wears it rapidly away, it will often decay with such speed that the steep face will be driven backward across the country until it finally appears in the form of an isolated table-land as is shown in the cut. Finally, when this table-land, decaying on its several sides, has been reduced much in area, it may appear in the form of what is called in the Mississippi Valley a butte. Such retreat-escarpments are often very conspicuous and beautiful features in the landscape. Excellent examples of such structures occur in horizontally disposed strata on both sides of the Mississippi and in the Saxon Switzerland, where they afford the table-like rocks of that beautiful district—isolated eminences, which, in that region of ancient warfare, are often crowned by fortresses. Such buttes, or tables of rock, only occur where the strata of a river valley lie in a horizontal attitude and where hard beds and soft are intermingled. Where the rocks of varied hardness depart very much in their attitudes from the horizontal, they greatly affect the flow of the stream as it wears down its bed, in the manner indicated

Cañon of the V a Mala Switzerland

(Showing the work done by a large torrent on rocks of close texture which are readily eroded by the stream)

by the accompanying figures. Thus the position of a stream in a valley where the rocks are steeply inclined is determined by the various inclinations of the strata.

All normal rivers where they discharge into the sea construct more or less extensive terrace-like deposits which receive the name of deltas. These accumulations are made up, in the main, of the detritus which finds its way to the bottom as soon as the flow of the river-water is arrested by its mergence in the sea. In part they are composed of the remains of marine animals and plants which are more or less abundantly developed on the mud flats at the *debouchure* of the stream. The deposition of the mud from the river-waters is more quickly effected than would otherwise be the case, through the peculiar effect which the salt in the water has in throwing down suspended materials. Those who are familiar with the operations of the chemical laboratory know how much more readily fine sediment is precipitated when the solution contains a little saline matter. Hence it comes about that the river mud rarely appears in the sea at any great distance from the mouth of the stream. Certain great rivers, such as the Amazon, throw out such a vast tide of fresh water that it drifts away for scores of miles before it becomes mingled with the heavier water of the ocean. As soon, however, as the waves have churned it into mixture with the salt water, the mud quickly finds its way to the bottom.

A large part of the mud brought out by a river thus falls near the land; thence much of it is driven back by the waves against the shore, and through this embarrassment of alluvium the river has to struggle with frequent changes of its current. All the very great rivers of the world have these delta districts in which the stream has endlessly to struggle with the

embarrassment caused by the waste derived from the more inland country.

Although in its general character the delta district is a continuation of its alluvial terraces which bound the stream from the time it passes out of the mountain-torrents into the river, this district next the sea always presents certain important peculiarities, which have had in many regions a noteworthy influence on the destiny of the peoples. The broad low lands of the delta afford very imperfect boundaries to the current of the river. The stream is continually changing its path in its endeavors to find less obstructed ways to the sea. Sometimes these changes of channel take place with great rapidity and in a very frequent manner; the result is that the delta districts are commonly cut up into many distinct islands of varied size, separated from each other by swift or languid currents according as their paths are recently constructed or are in process of abandonment by the stream. These separate islands, cut off the one from the other by deep channels and often divided by extensive morasses, afford natural strongholds more suited to the development of nascent civilizations than the steep-walled natural fortresses which abound in most inland countries. The soil of these delta islands is commonly very fertile. The streams generally abound in fish, and thus the inhabitants of such districts are readily provided with means of subsistence. Moreover, these estuaries of rivers generally communicate freely with the sea, and navigation, beginning at first with small boats, readily extends until it takes on the form of oceanic commerce. Holland, the deltas of the Rhine, of the Nile, and those of a number of Asiatic rivers, are thus the sites of very ancient and prosperous peoples who attained a considerable civili-

zation before the interior districts, less fertile, more subject to the incursion of enemies, and deprived of access to the sea, attained any thing like a high place in the arts of life.

So far we have considered the history of a stream where it has been left free from all natural interference to development. In such conditions, its basin is shaped as the concurrence of the erosive and corrosive forces may determine. In fact, few river-basins enjoy any such immunity from disturbing conditions. Their sensitive streams are variously affected by geological influences of an external sort. As these invading forces profoundly affect the form of river-valleys, we may take a glance at their nature. The most common disturbing influence which may affect a river-valley of considerable area arises from the construction of mountain-ridges across the path of its streams. It was once supposed that mountains were suddenly formed. It is now clear that in most, if not in all, cases they have gradually grown to their present height. Now, as the greater number of our mountains lie in the paths of streams which existed before the elevations were formed, it follows that our rivers which intersect mountain-ridges have had to wrestle with the barriers produced by the elevations. It may in cases have happened that the ridge or wall of a mountain has been suddenly uplifted across the path of a stream, but in most of the cases where we can trace the history of the contention between ridge and stream, we find that the elevation has been formed with such slowness that the river has kept open its channel across the line of the developing obstruction. This leads us to the conclusion that mountains are never, to any extent, barriers to the path of rivers; they probably, in most cases, grow so gradually that the streams may keep their ways open

through the obstacle which they tend to interpose. The part which mountains play in the history of rivers is thus limited to a narrower field than we should at first suppose. They affect the path of rivers by changing the inclination of rocks and so directing the swing of the streams. They also serve

Dunkar Spiti India

(Showing mountain wall, talus leading to valley, and stream embarrassed by débris.)

to maintain the torrential portion of a river-system, and so afford a ground whence the stream may obtain the alluvium necessary to make the plains which border the lower part of its course. As we have seen, a chemical action which goes on in the material of these delta-districts serves an important purpose in the economy of the earth's surface. Were it not

for the continuance of the mountain-building forces, the torrents, owing to the rapid down-wearing of their beds, would soon cease to afford such detrital material. The combined machinery of torrent and mountain so operates as to maintain the supply of detritus required by the needs of the sea for the

View into a Mountain Gorge

(Showing the distribution of the torrents of the upper part of the valley.)

maintenance of organic life in its depths and for the deposition of strata on its floor.

There are other and more formidable geologic agents tending to modify river-basins; the chief of these are glaciers. When a glacial period comes upon a country, the sheets of ice are first imposed upon the mountain-tops, and thence the

ice creeps down the torrent- and river-beds far below the snow-line, in a manner now seen in Switzerland and Norway. As long as the ice-streams follow the old torrent-channels, they act in something like the fashions of the flowing waters, to gouge out the rocks and deepen the valleys; but as the glacial period advances and the ice-sheet spreads beyond the mountains, enveloping the plains as well, when the glacier attains the thickness of thousands of feet, it disregards the valleys in its movement and sweeps on in majestic march across the surface of the country. As long as the continental glacier remains, its tendency is to destroy the river-valleys. The result of this action is to plane down the whole land, and, to a certain extent, to destroy all pre-existing river-systems. During the last glacial period, the old river-valleys were to a great degree worn away, and the remaining portion of their troughs was to a considerable extent buried beneath a thick coating of *débris* which the ice had worn from the surface of the land and dropped upon that surface as it retreated. The result is that in all countries which were affected by the last glacial period, the river-valleys have only here and there, and in all cases imperfectly, returned to their ancient beds. Ever since the ice went away, they have been engaged in a struggle to restore their ruined ways. As yet, this work is most imperfectly accomplished, and even if a glacial period should not return to the northern part of North America for several million years, the task of restoring the river-systems to their original aspects would not be completed.

We see a simple indication of this confusion of the old drainage brought about by glacial action, in the vast number of lakes lodged within depressions of the surface in New England as well as in all parts of the glaciated district. We

have only to compare the valley of such a stream as the James River, which lies south of the glacial belt, with a New England valley, such as that of the Merrimack, to see the importance of the effects accomplished by a glacial sheet on the river-system. The valley of the James is entirely without lakes; every part of its area slopes downward toward the sea. In the valley of the Merrimack, there are hundreds of these water-basins. A very large part of its surface is occu-

Norwegian Fjord

(Showing the form of a valley shaped by glacial action.)

pied by lakes, which owe their origin to irregularities of the surface, produced by the last glacial period.

There is yet another way in which rivers may be naturally obstructed; this is by lava-streams pouring out into their valleys. In all volcanic regions, the river-beds are apt to receive great inundations of such material. When gigantic eruptions of lava, such as have occurred in the recent geological periods in Oregon and California, in Southern India, and in Eastern Europe, are poured out, the stream-beds are

apt to be gorged with this igneous material, it may be for a distance of a hundred miles from the volcanic vents. At first the river is dried up by the fiery torrent. When the lava cools it becomes solid, often much more resisting to water-action than the rocks originally underlying the stream. It generally happens that the lava-current is higher in the middle of its course than it is upon the margin. The result is that when the river begins again to flow its course is divided into two, part of the water flowing on either side of the lava-stream. As time goes on and the streams cut deeply into their new beds, they may leave the old lava-mass perched upon a hill,

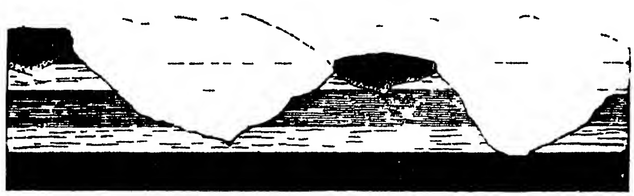


Diagram Showing Old River Channels on Top of Hills

(The upper dark layer shows lava, covering recent stream-beds, the faint lines show the topography when the lava-streams flowed.)

as shown in the diagram. It happens in California that these streams occupied by the lava contain gold-bearing sands, sometimes in very large quantities. The deposits of gold were accumulated before the lava came into the ancient river-beds. Miners have learned that wherever a mass of lava occupies the position indicated in the diagram they may reasonably expect, by excavating through the side of the hill, to strike the old river-channel, and beneath the cap of lava to find large deposits containing gold, which they may win more easily than the deposits in the beds of the existing streams. Owing to the extensive explorations which have been made in this search for gold in such positions, we have gained some

very important information from these obliterated, encumbered river-beds.

Perhaps the oldest evidences which we have of prehistoric man have been obtained from these mines driven into the ancient channels of rivers on the Pacific coast. A number of rude stone implements have been disinterred by these mining operations, which clearly prove that the region was extensively occupied by man One human skull has also

Volcanic Neck in the Valley of the Puerco

(Showing extent of erosion in the surrounding plateau, the sharp hills are the necks of old volcanoes, the cones of which have been worn away by the river action.)

been found in these workings, along with the remains of several extinct animals. The streams flow on either side of the old lava-current, and as they cut but slowly into the subjacent rock, we are able with safety to infer that these remains of man have been in existence for twenty thousand years or more. In Central France, near by the town of Le Puy, similar lava-streams also contain buried human remains. In both these cases, the remains of man have been found associated with those of extinct animals; which fact serves to show that the conclusion we draw as to the antiquity of

man, from the erosion which has taken place since the lava-current flowed, is well founded.

Although the rivers have to maintain a battle with many obstructing actions due to natural causes, there are only two circumstances derived from the revolutions of the earth's surface which seriously affect their history, at least in a permanent way. Where the rainfall of a country undergoes considerable variations, as appears always to be the case in the course of long geological periods, the streams necessarily find their volume diminished or increased, sometimes in an important degree. However much the rainfall may vary, the architecture of a river, the position of its branches, the distribution of its torrent and alluvial sections generally remain essentially unchanged. Even where the continent on which a river lies is greatly elevated beyond its original height, the system of the streams remains as it was before. Thus our rivers are in many cases the oldest features on the earth's surface. The upper waters of the Tennessee, for instance, especially those of the French Broad River, have apparently endured since the earliest ages of which we have any distinct record in the great stone book. They seem to have flowed at the beginning of the Cambrian time, and their channels have borne their floods to the sea during periods in which the continent of North America has undergone vast changes in form. Certain groups of fishes, such as the gar pikes, which probably had their cradle in these waters, have apparently dwelt in them continually since the Devonian time.

The only conditions which actually lead to the destruction of a river-system arise either from the imposition of a glacial sheet on the surface of a country or from its submergence beneath the level of the sea. We have already seen that the

interruption brought about by a continental glacier on the streams in the country over which it extends is usually but temporary. In a like manner, the submergence of a great valley beneath the sea-level is not apt entirely to destroy its basin. When the surface of the continent recovers its position, returning to the state of dry land, there is generally enough left of the form of the basin to cause the stream, at least in a general way, to follow its ancient paths.

With the foregoing brief sketch of their mechanism, we will turn our attention to the relations between the civilization of man and the system of the rivers. Nowhere else in the physical machinery of our earth is the influence of the hand of man so well shown as in the conditions of rivers. Nowhere else are his destructive or conservative powers so important. The effect of man's action upon rivers is in the main due to the fact that his occupancy of the earth leads to the removal of its forest covering. We have already incidentally noted the relation of trees to the immediate bounds of a stream; we have seen that the woods are continually pressing upon the margins of a river, causing it to sway to and fro, and tending always to narrow its channel. This is only one, and perhaps the least important, of the effects exercised by forests on the regimen of the greater streams. It is necessary to consider the action of forests over the whole basin of a river, in order to see the magnitude of their influence on the action of these waters.

The valleys of most rivers are forest-clad. Whether these forests have the gigantic growth characteristic of fertile districts in the tropics and the temperate zones, or take the shape of stunted woods such as extend far toward the poles, they in all cases form beneath their branches, and above the soil, a thick, spongy coating, which affords a natural reservoir

for the rain-waters. In most regions, this forest-sponge has a depth of more than a foot; it not infrequently attains a thickness of two feet or more. It can commonly take into its interstices a rainfall of three or four inches in depth, or from one-sixth to one-tenth the ordinary annual supply. This water is slowly yielded to the brooks; it often requires weeks for a single torrential rain entirely to escape into the open channels which bear it to the sea. Moreover, the fallen trunks and branches of the trees clog the forest-shaded rivulets, making little pools, which serve still further to restrain the outgoing of the waters. Our beavers, at one time the most widely distributed of our larger animals, at first making avail of these natural ponds formed by fallen timber, learned in time to construct more artful dams so as to retain extensive basins of water. Thus, in the natural condition of the North American rivers, as well as those of most other countries, before man began to clear away the forests, the woods constituted a great system of reservoirs, in which the rains were retained into the period of intervening droughts. In this state of the surface, the main channels of a river-system were continually the seat of streams of moderate flow. These channels were no wider than was required by the rate at which these forest-impounded waters escaped.

When man resorted to the soil as the source of his food, he began to clear away the forests and by tillage to destroy the spongy covering of the earth which they created. With the advance of civilization, all the great valleys on the northern temperate zone have been to a considerable extent deprived of their forest-covering. In this new state of the surface, the rain-water is no longer held back as it was of old, but flows quickly over the surface of the soil and enters the

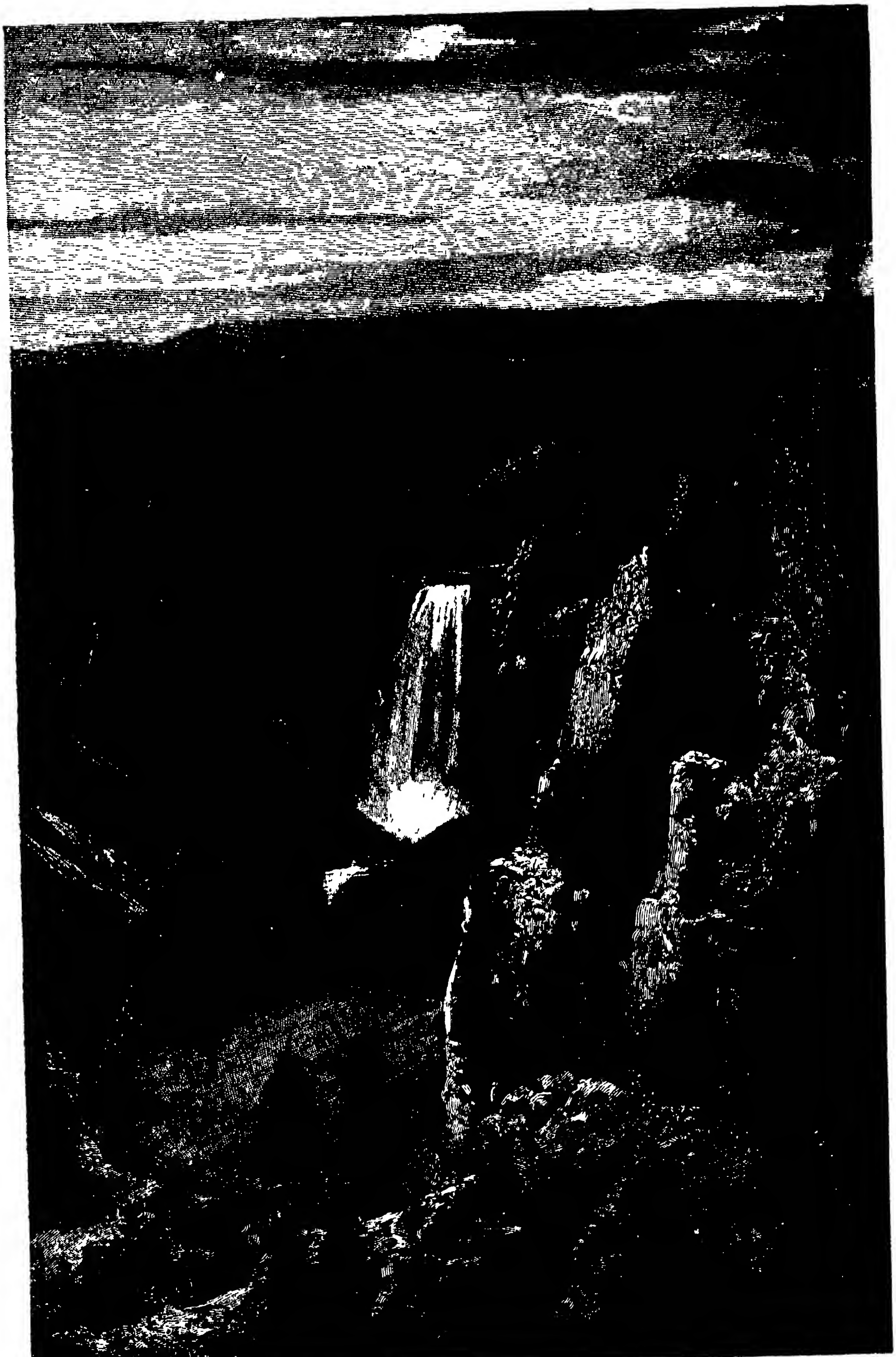
water-ways. The result is that all the old channels bear, in times of flood, a body of water far greater than that which was put into them before the forests were cleared away. They have been compelled to widen their channels by cutting away a strip of the alluvial land on either side. Thus, in the case of the Ohio River, the bed occupied by the flood-waters has, since the beginning of the present century, been widened to the amount of about one-fifth of its total diameter. Despite this widening, it is now unable to bear away the flood-waters yielded to it by the extensive tilled surfaces of its basin. In times of flood it rises higher than of old and spreads devastation over a wider area of the alluvial plains. In times of drought the stream shrinks within its waste of encumbering sands and becomes unnavigable.

In the present condition of the Mississippi valley, these floods and droughts seriously affect the interests of man. There, as in all other civilized countries, the great seats of population tend to gather on the river-banks. The alluvial lands are in all cases singularly fertile; and the streams themselves afford natural ways of transportation, the value of which does not seem to become lessened by the great extension of railway systems. In the present condition of these valleys, the fitness of these streams for navigation is progressively diminishing, for both in times of flood and in periods of drought they are unsuited to the uses of commerce. Moreover, in the flood periods, the streams are a very serious menace to all the towns which are gathered along the river-banks. As yet, we have only seen the beginning of these evils; for notwithstanding the extensive settlements in the Mississippi valleys, more than half their original forest-covering remains. When, with the rapid increase of population, these river-

basins become as thoroughly subjected to the uses of man as are those of Europe, we have yet greater ills to apprehend.

The problem of the Mississippi valley is one of national importance. By far the greater part of the food-producing capacity of our continent lies in the basin of that great system of rivers. It is therefore worth our while to consider the method by which this area can best be brought to serve the needs of man without imposing a serious burden on his arts. Although it is impossible in these few pages to consider the way in which this great task may be accomplished, it is perhaps worth while to note the general conditions which have to be met in this and other great valleys if that end is to be secured.

In endeavoring to meet the evils which arise from the removal of forest-covering from the surface of a country, we find that the difficulties to be considered are as follows: First, those which arise from the diminished restraint put upon the movements of the water which comes to the earth's surface in times of heavy rain or of melting snow. Next, the evils due to the rapid wasting of the soil, which, in its unprotected condition, is readily washed into the stream-beds. The first of these evils gives rise to serious destruction of wealth and to the interruption of industries. The second threatens the loss of that precious soil-covering on which depends the relation of all land life, that of plants and man and beast, to the surface of the earth. It is clearly evident that we cannot hope to preserve any considerable portion of our forest lands from destruction. The need of subsistence such as is drawn from the soil is immediate and overwhelming. During the last century, Europe has been able to preserve a portion of its forests, and indeed to win extensive areas back to the condition of woods, for the reason that it could draw supplies of



Gorge and Fall of the Yellowstone River.

food from this country; but when our American soils are occupied, it does not seem likely that other parts of the world will afford any such opportunity for obtaining foreign grain. At most, we may expect that a small area, perhaps not exceeding one-tenth of our original forests, may be retained in their present shape, in order to afford supplies of timber. It is therefore necessary, if we have to control these flood-waters at all, to devise some means by which we may imitate the old natural system of water storage which the primeval woods afforded. There is but one method by which this end may be accomplished, viz.: by creating artificial reservoirs in which the waters may be for a time retained during the period of floods.

Some years ago, a distinguished engineer, Mr. Charles Ellet, suggested a system of controlling the floods of the Mississippi valley. He proposed to build certain dams in the upper waters of the Mississippi system, in which, during the times of flood, a considerable part of the flow might be impounded, to be discharged into the channels at such times as was needed to maintain a navigable depth of water. There are certain objections to the details of the system proposed by Mr. Ellet, the principal of which is that the existence of very large reservoirs would add another source of danger to those which the floods now inflict upon the valleys of these streams. It is difficult cheaply to build retaining dams so that they may be absolutely secure from the risks of giving way. The bursting of such a dam in time of flood might prove peculiarly disastrous.*

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*The foregoing statements concerning the danger of dams in river-channels were written some years ago, and were then based on general considerations, as well as on the experience which had been gathered from numerous minor disasters from the bursting of reservoirs.

It seems, however, possible that a slight modification of Mr. Ellet's plan would more effectively accomplish the end he had in view, without creating the risks above noted. For in place of half a dozen great artificial lakes, we should adopt the plan of having many thousands, or tens of thousands, of smaller reservoirs, so arranged that no one would, by its bursting, lead to the destruction of any other. We could by this means retain on the surface of the land a very considerable part of the flood-waters which now prove disastrous to the valleys below. Computations, which it would be out of place to present in a writing of this nature, have shown me that it would apparently be possible, with an expenditure of less than fifty million dollars, to diminish the rise of floods at Cincinnati to the amount of at least twelve feet, and at the same time secure to that river a good degree of navigability during the whole of the dry summer season. To control in a similar manner the floods which ravage the valleys of the other large tributaries of the Mississippi, would perhaps require a total expenditure exceeding one hundred million dollars. The maintenance of this system would necessarily be costly; it would perhaps amount to as much as ten million dollars a year. It seems, however, possible that for this cost we might obtain a substantial immunity from the worst destruction accomplished by our floods. Even if this system should be adopted, it would be necessary, decade by decade, as the process of forest removal advanced, to extend still further the area of the storage reservoirs.

While the proper control of the Mississippi drainage system is of great importance to the nation at large, to the states which border upon its waters it is a matter of vital

necessity. Whether this great task is to be undertaken by the Federal Government or by associated commonwealths, there can be no question that it should be at once entered upon. Every year increases the magnitude of the necessities and the difficulty of devising means to meet them.

The great disaster in Pennsylvania which occurred on the 1st of June, 1889, afforded a startling illustration as to the dangers which may attend on the storage of large masses of water in our river-valleys. To understand the measure of this danger we must remember that every stream-bed is adjusted by the processes which lead to its construction to the carriage of an amount of water which it is required to bear by the ordinary processes of nature. When, as in the Pennsylvania accident, a great body of water is by the swift destruction of a dam delivered to the channel, it with difficulty moves down the insufficient water-way, assuming as it sweeps onward almost the form of a wall. The impetuosity of the current causes it to rend from the path it pursues a vast quantity of stones and mud, which so thicken the fluid and encumber its way that it does not flow as water ordinarily does, but acts rather like an avalanche of snow or ice. The wall-like character of the flood's advance may be retained for scores of miles below the point where it is delivered to the valley. Unlike ordinary floods, the tide does not rise gradually, but comes with a single overwhelming blow.

It happens that the disaster above referred to was due to the outbreak of a mass of water which was held in its dangerous position, not to meet any grave public need, but for the purposes of sport. It is easy to dispose of such cases by well-enforced laws which will prevent the enclos-

ure of fish-ponds of any such size as to endanger lives or property in the valley towards which the waters discharge. It must be recognized, however, that in all our river-valleys it is necessary to store in reservoirs large quantities of water which serve important public needs. For water power, for the supply of cities, or for the maintenance of navigation in our rivers, it will be necessary to construct many such basins. Although there must be always some element of danger wherever these reservoirs exist, the risks may easily be reduced to a minimum. Rarely indeed is it warrantable to have the depth of the water exceed twenty feet in the part of the basin next the dam. If under these conditions the storage is insufficient, a number of dams should be constructed, one above the other. It is the habit of our engineers frequently to construct dams where the retaining-wall is relatively thin, the greater portion of the barrier being composed of earth. It frequently happens that these masses of earth become thoroughly water-soaked. In such cases it is often a mere pulpy mass, like quicksand, which adds but little to the strength of the dam. If now the single wall is ruptured, the whole obstruction may readily break away. Two good masonry dams a sufficient distance apart, well founded on rock beds, the interspace filled with compact earth and the upper side protected by a sloping bank of dense clay, will commonly secure the structure against any mischance save that which a great earthquake might bring to it; but, with any conditions of engineering care, no such vast reservoirs as Mr. Ellet proposed should be constructed.

Although the American theory of government looks to the initiative of the individual for the most of the acts which in other lands are accomplished by the state, it still has to con-

fess that certain classes of work are only accomplishable by federal control. Our great river is fast becoming a common enemy of our people; it is our duty to restrain its ravages as we would those of any other foe of the state. During the present century the forest area of the Ohio valley has probably been diminished by the amount of one-fourth of its original area. More than this proportion of the country has been cleared of its wood; but in certain districts, as on the Green River in Kentucky and in portions of Tennessee and other States, the woods have gained upon areas which were previously prairie land. The result is that probably three-fourths as much forest now exists as when the country was first settled. With the rapid advance in population it seems quite certain that by the middle of the next century the forest area will be reduced to less than one-fourth of the extent it now occupies. The effect of this change upon the magnitude of the floods cannot fail to be great.

There is another economic and social problem connected with rivers, which is just receiving attention in this country, though it has long occupied the minds of engineers and statesmen in other lands. This is the question of irrigation to be applied to the desert fields of the region in and about the cordilleras of North America. In the present state of the rainfall in the Rocky Mountain districts and the neighboring portions of the continent, the soil is generally unfit for agriculture on account of the scanty rainfall during the warmer part of the year. The rain generally falls in winter season, and passes from the surface of the country through the steeply inclined river-beds before the season of growth approaches; the result is that the earth is occupied by a scanty herbage which gives an indifferent support to cattle,

and refuses to reward any form of tillage. It is hardly too much to say that one-third of the area of the United States, excluding Alaska, is more or less completely sterilized by summer droughts, and a large portion of the remaining area suffers grievously from frequent dearth of rain. There is but one way of mitigating this evil, but one way in which a large part of this soil can be fitted for the plough, and that is by storing a portion of the winter rains in reservoirs, leading the water forth at the fit time upon the adjacent lands by means of irrigation canals. The general preliminary studies of the cordilleran district made under the direction of Major J. W. Powell, director of the United States Geological Survey, have served to show that a large part of this field is winnable to tillage by the simple and relatively inexpensive method of storing and distributing the natural rainfall of the country. There seems a chance that we may gain to agriculture from these desert lands a region having the food-producing power of at least six States the size of Illinois. It seems likely that by the application of this beneficent system we may secure in the magnificent climate of that elevated and salubrious country the food for from ten to twenty million people.

In large part, this irrigation system may be accomplished without the construction of reservoirs to retain the winter waters ; but the effective execution of this project will require the construction of very many artificial reservoirs for the storage of water accumulated in time of rain, to be made of service in the dry season. At first sight it may seem that such a system promises to give rise to disasters such as that which overwhelmed the city of Johnstown and the neighboring villages of the Conemaugh valley. Although, as before

Pilling's Cascade, Utah.

(Showing type of waterfall in massive rocks which are cut by joints. U. S. Geological Survey.)

remarked, all reservoirs are in their way dangerous,—as for that matter are most of our engineering works, when carelessly administered,—there are particular reasons why a system of storage basins in the Rocky Mountains can be constructed with much less danger than in other regions. In the first place, long-continued torrential rains such as lead to the Conemaugh accident are uncommon in the Rocky Mountain district. Cloud-bursts occur in particular districts; but they are of brief duration, generally limited to very small areas. It is generally easy in that country to choose sites where short, well-founded dams will retain the water over large areas in such circumstances as would lead to no great disaster in case the barrier were broken. Moreover, the country is now essentially unfit for the uses of man except in the temporary work of mining; and even if disasters were frequent, while in fact they are likely to be but of seldom occurrence, we could maintain that the interests of man were well served even if the population made possible to the country by irrigation were to a certain extent endangered.

The lessons of experience clearly point to care in the selection of the sites to be occupied by storage reservoirs which are intended to serve the irrigation works of the Rocky Mountains; the lessons indeed should be heeded in all countries. In the cordilleran district, however, there is reason to hope that the construction of these dams may be under the supervision of able engineers, who will guard the folk to be from the ravages of these unnecessary floods. Although the dangers are manifest, the means of avoiding them are equally clear: it requires only the courage to spend the money required to secure safety, to make the proposed irrigation basins of cordilleras as safe as good railways or

well-constructed houses. The lesson derived from the Conemaugh disaster is not that we should avoid such engineering works as brought about this disaster, but that we should take pains to secure the public against the mischances which faulty construction may bring upon them.

THE INSTABILITY OF THE ATMOSPHERE.

Contrast between Conditions of Ocean and Air; Mingling of these Elements; Dependence of Organic Life upon them.—Maintenance of Temperature; Conditions of other Bodies in Solar System; Conditions of Moon; Way in which Heat is Retained; Conditions of Temperature in Past Geologic Ages.—Evidence of Long-Continued Equilibrium in Atmosphere both in Heat and Constituents.—Elimination of Oxygen and Carbon from Air; Methods of Replacement.—Circulation of the Air; Cause of Movements; Tropical Winds; Trade Winds; their Permanence; their Origin.—Direction of Movement of Trade Winds; Cause of Inclination to the Equator.—Effects of Irregular Distribution of Heat; Compensating Influence of Ocean Currents.—Inconstant Winds; their Origin; Land and Sea Breezes; East Wind of Atlantic Coast.—Variable Winds; their Origin; Experiments; Cause of Whirling Movement; Various Conditions of Origin.—Tornadoes; Origin of; Effects of.—Speed of Movement and Appearance of Tornadoes; Origin of Destructive Action; Width of Path; Ways of Avoiding Accidents.—Distribution of Tornadoes; Effects on Forests.—Cyclones; their Origin; How Ships may Avoid them.—Effects of Cyclones on Shore; in Bay of Bengal; in Florida.—General Economy of Atmospheric Movements.

The solid and relatively fixed mass of the earth is wrapped about by two great envelopes, the atmosphere and the waters, each characterized by a certain instability. The water-envelope is mainly gathered into the basins of the seas, where it has definite boundaries and a distinct uppermost surface. Still, a small portion of the water is constantly in the air; or, proceeding from the air to the earth, is making an often long-continued and roundabout journey over or through the superficial parts of the earth's crust on its way back to the seas. All our rocks contain a portion of water on its way to the ocean, or temporarily imprisoned in their interstices; so we may fairly regard the water of the earth as constituting an

envelope of its whole surface, though the greater portion of the substance is in the sea-basins. The envelope of the air is also somewhat peculiarly distributed over the earth's surface, but the irregularity is much less pronounced than in the case of the water.

If the water came to a state of rest, it would all return to the seas and lakes, and would cover only three-fourths of the earth's surface; and under the same conditions of rest the air would cover the whole earth, but it would be densest where it lay on the surface of the sea, and thinnest over the surface of the land. These two envelopes are somewhat commingled; the water is more or less mixed with the air and with the solid parts of the earth, and the air is to a certain extent commingled with the water and enters even as much as the water into the interstices of the rocks. Both these envelopes are capable of taking some part of the other substance into their masses, but they differ much in the measure of this capacity. Water can take a large amount of solid matter into suspension by dissolving it, while the air can only receive and retain foreign matter when that matter is in the state of gas. We might very much extend this list of related and contrasted properties of the two great oceans, but for our purpose we need to note only the last and most important feature of contrast. The air is gaseous; it is normally composed of several commingled gases, while the water is a fluid having a more definite constitution and containing other substances in a somewhat unessential way.

All the possibilities of organic life which the earth presents, and which, so far as we can conceive, any other sphere can afford, depend upon the coincidence, on the surface of a sphere, of these contrasted and yet related masses of air and

water. It is true that other materials, such as carbon, are also among the necessary conditions of organic development; but, though these mineral substances are found everywhere in the physical universe, they can only come into conditions where they may enter upon the form of living beings when they are associated with the enveloping oceans of air and water. Where these envelopes are wanting, as on the surface of the moon, the sphere remains without the possibilities of life. Even where these envelopes may happen to exist, it is only with the conjunction of certain temperatures that life can possibly develop. If the heat at the surface of the sphere remains below the freezing-point, or if it attains a temperature exceeding 150° F., the conditions of life disappear. Although the organic form of matter depends upon the conjunction, on the surface of a planet, of water, air, and a certain temperature, the dependence upon the air appears to be the most immediate, for to that element we owe not only the oxygen, but also the preservation of the temperature which makes life possible.

The maintenance of the temperature necessary for organic life on the earth's surface is a problem of singular difficulty. In the spaces between the planets we have a temperature of several hundred degrees below the zero of Fahrenheit, and in the sun a temperature which is probably to be measured by tens of thousands of degrees. The difficulty was to preserve on the surface of the earth a temperature which should remain, over the most of that surface, through all the geological ages, above the freezing-point of water, and yet below the temperature of one hundred and fifty degrees. We see the immediate effect of this combination of air and water when we consider the condition of the moon's surface. That sphere

is without either atmosphere or oceans, yet in many other regards is much like our earth ; but owing to this want of the envelopes of air and water it has remained a perfect desert. The heat flies away from it as fast as it is received from the sun ; even during the long day it is doubtful if the temperature of the moon's surface rises above zero of Fahrenheit, and in the night it probably falls to near the temperature of space, a hundred degrees or more below the point which is ever attained on the earth.

All those who become keenly interested in the final conditions of the earth's surface find themselves naturally led to exercise their constructive imaginations in conceiving the conditions of other spheres than our own. It is therefore interesting to note that the atmospheric envelope appears to be a feature common to all the planets of our solar system which are near enough to afford us opportunities for observation. The sun itself has a vast atmosphere, though this envelope is intensely heated, and contains many substances in the form of vapor which are solid bodies on our earth. The planet Venus appears to have an atmospheric envelope, and is surcharged with cloud in such a measure that only one or two lofty elevations project above the enduring field of vapor. Mars evidently has an atmosphere of considerable density, which apparently yields from its clouds frequent falls of snow. These snow-falls may be observed in the proper season extending far south from either pole. Jupiter and Saturn appear also to have deep envelopes of air.

The only well-ascertained exception of the principle that the spheres of our planetary system are wrapped by atmospheric coverings is found in the case of our own satellite. Although many observers have fancied they beheld phenomena

indicating a trace of such an envelope on the moon, it now appears clear that there is no gaseous covering to this body. If any ever existed, it has been absorbed in the mass of this desolate world. The entire and ever-abiding desolation of that sphere can only be explained by the absence of the gaseous envelope on which all planetary life must inevitably depend.

The atmosphere serves to retain the heat of the sun by virtue of a singular feature of its structure. The direct rays of the sun pass through it to the surface of the earth with ease, and heat the superficial parts of the land and sea. These warmed surfaces seek to discharge their heat directly back into the celestial spaces by the process of radiation. If the way out were as easily traversed as the way in, the heat received from the sun would be removed as fast as it came, and the earth's surface would remain at the temperature of space; but the air is a trap. The radiant heat from the earth's surface cannot traverse it with the same speed as the direct rays from the sun; hence the layer of air next the earth's surface becomes warm in the measure which is necessary for organic life.

It is not easy to appreciate the delicacy of adjustment which is required to establish this temperature demanded by organic life, and to maintain it through the geological ages. Even in the permanent heat of the equator, the zone of life-killing cold lies but four miles above the surface of the sea. As soon as night comes on, this dead-line begins to descend toward the surface; by morning it may have fallen to within three miles of the sea-level. A week of continued night would lock the tropics in a deadly frost and make an end of its land-life.

The geological record shows us clearly that, in the hundred million years which have elapsed since the plants and animals of the land have been in existence, the regions of the tropics have never been subjected to serious frost. From time to time during the course of the earth's development, glacial periods have originated ice-sheets about either pole. These sheets of ice have crept down toward the equator, often attaining half the distance which separates the regions of greatest cold from the tropics; but the intertropical belt of land and sea, that great asylum whereunto resorts the life expelled from circumpolar regions by the glacial periods, never has been subjected to a deadly temperature. The evidence that goes to show this is simple and conclusive. Certain groups of plants—as, for instance, the tree-ferns—and many orders of animals are extremely intolerant of cold, yet the fossils show us clearly that, from the early geological ages to the present day, these forms have been continuously occupants of tropical districts. A very brief period of cold would have placed them among the extinct creatures of the past. An equally brief period of heat, provided it brought the atmosphere and the waters to a temperature above 150° Fahrenheit, would likewise have made an end of organic life upon the earth. It is therefore clear that the atmosphere is a conservator of heat, and that in this conservative work it has not failed in its function since the dawn of geological history. It is almost equally clear that the climate, in the earliest periods of the earth's development of which we have any record in the rocks, was, in a general way, essentially like that of the later geological periods, and even that of the present day. In certain peculiar conditions glacial periods have now and again extended the ice-sheets from the poles for a considerable dis-

tance toward the equator. In the periods which have intervened between these times of glaciation, the temperature of high altitudes has permitted plants which were clearly sensitive to cold to live in regions within the Arctic Circle. But apart from these great cycles of change, which give us in succession extreme and temperate climates about either pole, the evidence goes to show that the temperature of the earth has not undergone great variations.

If our nearest companions in space, the planets of the solar system, have any organic life developed upon them, they must owe the conditions which permit such beings in the main to the peculiar organization of their atmosphere. Thus in the case of Mercury and Venus, which are very much nearer the sun than the earth, the temperature on the surface of those spheres would, save for a possible compensation which its atmosphere might afford, be far too elevated to permit organic life to exist. If the atmospheric conditions were the same as those of our own earth, then the heat even in the circumpolar regions of these planets would probably attain at certain seasons of the year a temperature above that of boiling water, while in their tropical districts it would probably never fall below that point. It appears, however, as before remarked, that Venus is deeply cloud-wrapped, and it may be that under the shelter of such a cloud mantle the fierce rays of the sun would be in large measure fended off from the surface of the planet. In the case of the planets which lie farther away from the sun than our own, it may be that, owing to the greater thickness of their atmosphere, the relatively small amount of the sun's heat maintains the surface of the spheres in conditions which would make organic life possible.

There can be no question that this evidence leads us to the conclusion that the mass of the air has remained essentially the same during the period of that inconceivably enduring past recorded in the fossiliferous rocks. Any considerable change in the volume of the atmosphere, without a coincident alteration in the amount of heat it received, would be followed immediately by a change in the temperature of the surface on which the air lies. Whenever we climb a considerable mountain we make a practical experience of this protective effect of the atmosphere. For each thousand feet of that height—that is, for each considerable part of the atmosphere we pass through—we find the average annual temperature lowered by from three to six degrees. At the height of a few thousand feet above the equator we pass from the tropical climate, and enter the zone where frosts make many forms of tropical life impossible. A little higher we pass beyond the possibilities of life at all, and enter into the region sterilized by perpetual cold. On the other hand, if we had a basin excavated to the depth of ten thousand feet below the plane of the sea, in the equatorial belt, the average annual temperature on its bottom would so much exceed the present heat of the equatorial lands at the sea-level that even the most heat-enduring forms of life would find it excessive and would perish. In other words, to preserve the temperature of the tropics as it has been preserved from a remote period in the past, the total volume of the air must have remained for all time about what it is at present; at most it can have undergone but slight changes in volume.

This permanence of the atmosphere is the more surprising when we consider not its mass alone but also its con-

stituents. As is well known, the atmosphere of our earth consists in the main of nitrogen, a substance which has comparatively little direct relation to the chemical or organic work done upon the surface. This relatively inactive nitrogen amounts to about three-fourths of the weight of the air. With it are mingled two other very important gaseous substances, which, unlike the nitrogen, are of the utmost importance to animal life, and profoundly affect the physical history of the earth's surface as well. These substances are oxygen, which comprises about one-fifth of the weight of the atmosphere, and carbonic acid, a combination of one atom of carbon and two of oxygen, which exists in very small quantity at any one time in the atmosphere. At the present time the proportion of this substance amounts to a very small fraction of one per cent. of the total mass or weight of the air. These two gaseous materials, oxygen and carbonic dioxide, are constantly passing from the atmosphere to the earth's crust in such large amounts that it is very difficult to understand how the supply of them—a supply absolutely necessary for the important functions of the atmosphere—is maintained. Oxygen enters into the earth by the process of rusting and decaying which we see going on in the rocks about us, and in many other ways which are not manifest to the eye. Whenever a metal rusts, or a rock-mass decays, it almost necessarily happens that a portion of this oxygen becomes imprisoned in the earth's crust. The present store of oxygen in the atmosphere by weight amounts to about three pounds upon the square inch of surface, or about four hundred pounds to the square foot. In the processes of what we call decay—but which we would better term change—which have taken place since the beginning of the geo-

logical record, it seems certain that far more than the amount of oxygen now present in the atmosphere must have been imprisoned in the oxidized materials of the earth's crust.

As was long ago shown by the distinguished chemist, Henry Wurz, a very small amount of the iron pyrite contained in the earth's crust would, in decomposing, absorb all the oxygen in the atmosphere. The chemical actions which serve to take oxygen from the free air into the prison of the earth's crust are numerous, and the gates of that prison are rarely unbarred. Once confined in the rocks there seems, practically, hardly any way in which it can be set free again; at least the possibilities of its escape are so limited, as compared with the imprisoning actions, that we cannot look to them for an effective restoration of this element to the atmosphere. At first sight it may seem possible that the atmosphere at one time contained within itself, in a gaseous form, a much larger proportion of oxygen than it does at present. May we not suppose that all the oxygen which, in the course of geological time, has been bound up in the earth was, at the beginning of that time, in the atmosphere, the original store having gone on decreasing as it was drawn upon to supply the needs of the underground actions? But here, as before, the evidence from past life serves to show us that the chemical composition of the atmosphere has changed as little as its mass. If in the early geological ages there had been on our earth an atmosphere charged with oxygen in the measure which the above statements would require us to suppose, animals could not have breathed; for, as experiments show, they are little tolerant of any material increase in the proportion of this gas. There is thus, from these limited considerations, a reason to believe that the insects and batrachians of the Carboniferous

period found the air essentially the same as that breathed by their successors living at the present day. These considerations could be extended and enforced if space were at our disposal; but the reader may trust the geologist when he states that all the evidence indicates that the atmosphere, in times even antecedent to the Carboniferous period, did not contain a materially larger share of oxygen than it has at present.

The only way in which we can conceive the replacement of this life-giving oxygen, which the greedy earth is always claiming from the air, is through the action of the plants; each plant, in its process of growth, takes all the carbon of its woody matter from the air. This carbon it finds in the atmosphere in the form of carbonic dioxide—that is, a chemical combination where there is one atom of carbon linked with two atoms of oxygen. Absorbing this gas, it breaks up the union of the two elements, retains the carbon, and returns the oxygen to the air. In this way there is a constant return of the precious life-giving gas to the atmosphere. The carbon is, it is true, to a certain extent reunited with the oxygen when the wood decays; but in part this carbon goes into the rocks in the form of coal or limestone, and in so far it effects a substantial contribution of oxygen to the active supply on which all animal life depends.

If there were a source whence a supply of carbonic-acid gas could be obtained, it would be easy to explain the preservation in the atmosphere of both these substances which are so indispensable to organic life; for even the solar force operating through the plants would work to break up the union of the oxygen and the carbon composing this gas, and so afford a continual supply of these materials.

But now we find ourselves facing the great mystery of the atmosphere: Whence comes this ever-demanded store of combined carbon and oxygen? In what manner is it given to the atmosphere in such a well-adjusted measure that the plants always have their fit share of carbon, and the animals never any excess of the oxygen? The amount of this carbonic dioxide probably has never much, if at all, exceeded one per cent. of the atmospheric mass. Carbon is ever passing at a rapid rate from the air to the earth—our coal-beds are vast stores of it; our limestones, composed in the main of lime carbonate, contain far larger amounts than the coal; and in the decay of our crystalline rocks vast amounts of it are permanently laid away out of reach of the atmosphere. There can be no doubt that, since life began upon the earth, there has been taken from the air scores of times as much carbon as is now contained in the atmosphere. It was once supposed that this carbon was returned to the air in a regular and full measure by the action of volcanoes. These vents do, indeed, throw out a certain amount of carbonic acid as a part of their emanations, but it now seems clear that they cannot begin to maintain the balance against the forces which tend to lock carbon in the earth.

It was also for a time believed that the carbon now in our rocks, placed there since the beginning of organic life, was originally all in the atmosphere, and that it has gradually been taken thence into the rocks of the earth; but here again the fossils rise up and testify that the air in the most ancient days of land-life did not contain any such vast store of carbonic-acid gas. Careful observations show that the ferns and other allies of the plants which flourished in the time when the coal-measures were laid down will not exist in

an air containing a great excess of carbonic-acid gas, and the abundant air-breathing animals of that time certainly could not have withstood any considerable increase of that substance beyond what the atmosphere at present contains. We are clearly justified in assuming that at no one time was there in the realm of the air the hundredth part of the carbon which is locked up in the stratified rocks. The difficult problem before us is to find some source of supply whence the combined oxygen and carbon can be derived in uniform quantities, as the needs demand. If such a source of supply could be found, we might then assume that from it the plants, by decomposing the elements of the gas, found the source of the carbon which has been stored in the earth, and that in obtaining this carbon they replenished the oxygen of the air.

Defeated in the effort of finding a terrestrial source of carbonic acid sufficient to supply the ever-current needs of the atmosphere, physicists have of late been driven to the hypothesis that this material comes upon the surface of the earth from the celestial spaces. Dr. T. Sterry Hunt, in his essay on the chemical and geological relations of the atmosphere,* after showing that the atmosphere could never have contained the thousandth part of the vast stores of carbon which have been drawn from it, proposes the theory that the atmosphere of our earth is essentially a local condensation of the gases which are, in a very attenuated form, distributed through the realms of space. From this vast outer realm the carbonic acid enters the atmosphere by a process of diffusion, thereby maintaining an equal supply of the gas which is the source of all organic life. This combination of carbon and oxygen being broken up by the action of organic life,

* "Mineral Physiology and Physiography," p. 30 et seq., 1886.

the latter substance is set over to play its essential part in the support of animal life and in the chemical work of the inorganic world. Thus, as was suggested by Dr. Henry Wurz in 1869, the plants may be the agents by which the free oxygen is returned to the atmosphere after it has been imprisoned in the union with carbon. If this hypothesis be true, we would then have the following beautifully ordered series of actions: The celestial spaces, furnishing us the carbonic acid, afford at the same time solar force in the form of heat and light; the plants, making use of this force in their vital processes, break up the combination of carbon and oxygen, and so, not only supply themselves with material necessary for their sustenance, but preserve the balance in the amount of oxygen without which animal life cannot be maintained.

We cannot yet consider it proved that this balance of carbon and oxygen is preserved by the incoming of the combined material from the realms of space. There are, indeed, some difficulties to be explained before the hypothesis can be regarded as verified; yet it is by far the most satisfactory view which has been suggested as to the source of these aerial springs of life, which, though always drawn upon, seem never to run dry. There is, indeed, a fascination in the idea that our fuel, our daily bread, even the breath of life itself, as well as all force which is embodied in living beings, is constantly and regularly fed into us from these grim and seemingly inhospitable realms of space.

There is much support to be found for the foregoing hypothesis as to the source of carbonic acid, in the evident uniformity in the supply of both carbon and oxygen which has been given to our atmosphere from the earliest geologi-

cal times. Nothing could have so well maintained uniformity in the supply of these substances as the constant condensation of the materials from the spaces between the stars. If the restoration came through any such paroxysmal actions as are involved in volcanic explosions, it might well have happened that the variations in that amount contributed to the atmosphere would have been so great as to shock the delicate mechanism of plant and animal life.

It should not be overlooked that this hypothesis as to the supply of carbon and oxygen from celestial spaces to our atmosphere presents certain grave difficulties which have not yet been met. All our observations concerning the nature of the ethereal substance which occupies the interstellar spaces through which the suns and planets move, go to show that there is very little material having the properties of ordinary gas within this vast realm. Through space the planets evidently move encountering practically no resistance. It is therefore difficult to conceive how there can be any considerable amount of gaseous matter in the regions of space occupied by our solar system, for if such matter existed there, it should manifest its presence in the resistance it offered to the movement of the planetary spheres as well as of the comets which, owing to their small bulk, should show the effect of any materials even if they were present in an extremely diffused form. It seems to me possible that the carbon may come to the earth's atmosphere in the form of small meteorites containing carbon, which, being raised to a high temperature by the friction which they encounter in their passage through the air, are completely burned in the upper levels of the atmospheric envelope. We know that a good deal of carbon is contained in many meteorites, and that at certain times

of the year vast numbers of these bodies enter the air and are burned up before they attain the surface.

We have now considered the stability of the air in its larger aspects; we have seen that it has probably remained substantially unchanged from an inconceivable period in the past. We may safely term this period a hundred million years; though as such a duration is quite inconceivable by the human mind, we do not help our statement by putting it in this form. Let us now turn to the more familiar phenomena connected with the atmospheric movements which we term winds.

Both the aqueous and the aerial envelopes of the earth's surface have a complicated system of circulation. In the water-envelope this circulation is accomplished in two ways. Within the sea there are extensive movements—those of the various classes of ocean-currents, which are mostly the product, directly or indirectly, of the atmospheric movements. When in the state of vapor, the water, borne about by the winds, circulates through the air until it finds its way back upon the surface in the form of rain, snow, or dew. These principal movements are brought about by the action of the sun's heat. A considerable part of the atmosphere is always contained in the water in what we may term a dissolved form, and so makes its way in the rain, in the rivers, and in the motions of the sea.

Although the winds are the most familiar to us of any of the larger phenomenal movements which take place upon the earth's surface, it was long before men came to anything like a clear understanding of the causes which produce them. It was not, indeed, until the barometer was invented, and until that instrument came into common use, that it was possible

to begin a study of the causes which affect the motion of the winds. Although this instrument was given to us by the illustrious Torricelli in the seventeenth, it was not until about the beginning of the present century that the observations with it became sufficiently extended to afford a fair clew to the nature of the atmospheric movements. Even in the present day a considerable number of the problems which we encounter in the study of the winds remain unsolved; still the general laws which induce their movements are fairly well known, and it is possible to give the reader a clew to the more important facts concerning atmospheric currents. It should, however, be understood that the statements concerning the winds which can be made within the limits of this essay are necessarily brief, and cannot afford the reader more than the most general idea regarding the nature of these movements. It is not in our project to consider the physiology of winds, but only to view them as phenomena which affect our general conception of the atmospheric work.

We note at the outset that the winds are in a general way divisible into two groups—those which we may describe as continuous, and those which we may term variable. Though the line of separation between these groups is, as might be expected, obscure, it has a considerable value. The continuous movements of the atmosphere are represented by the familiar trade-winds which exist in certain parts of the open seas north and south of the equator. There alone, on the surface of the earth, do these movements of the air have the permanence which we find associated with the larger operations of nature. The permanent winds of the upper atmosphere are probably more continuous and more extensive than those which are found upon the surface; but owing to their

height, and therefore to the difficulties of observing them, their directions and velocities are not so well known as the less enduring currents which affect the very surface of the earth. We can best illustrate the nature of the trade-winds by an imaginary journey from high altitudes toward the equator. A voyage such as is taken by every ship from British ports, or from those of New England, on its way around Cape Horn, or the Cape of Good Hope, gives the observer an opportunity to study these winds. At the outset of such a cruise the mariners find themselves in a region where the wind "bloweth as it listeth," the uncertainty of the direction being the only foreseeable feature of the movement. There is in these winds a certain predominance of a movement to the east, which the mariner takes into account; but in the great atmospheric churn of the Northern Atlantic all the laws of wind-movement are concealed by the contentions between the diverse atmospheric influences which exist there.

As the ship works to the southward into the open sea, and comes near to the thirtieth parallel of north latitude, we find that the variable winds gradually die away, giving place, after a brief interval of calms, to a constant breeze from the east and north points of the compass. At first these winds blow in a faltering way; but shortly they increase in steadiness, and in the speed at which they move, until the whole air flows toward the southwest. This steadfastness of movement is maintained over the zone which occupies all the space of the sea except a relatively narrow belt near either shore. Very rarely do wandering disturbances mar the uniformity of this aerial tide, and, at most, they cause only a temporary break in the otherwise continuous movement. After passing through this belt of gentle easterly winds for a north and south dis-

tance of about thirteen hundred miles, or to within two or three hundred miles of the equator, we find ourselves gradually entering a belt of calms, generally about three hundred miles in width. Through this region the sails are filled by the most fitful winds of the seas, severe thunder-storms with fierce squalls, alternating with long periods when there is scarcely any movement in the air. Availing himself of the perplexing accidents of the atmosphere, the mariner works his way through this disturbed region of alternating tempests and calms until he strikes the southern trades, the exact counterpart of the winds of the north. These southern trades blow from the southeast, as those from the north of the equator from the northeast. The belt of southern trades has about the same width as that traversed in the north. Passing through it, the ship encounters again in the Southern Atlantic region a district of partial calms about the tropic, south of which it again enters upon a region of variable winds.

A north and south journey in the Pacific shows us the same arrangement of the permanent and impermanent winds which we find in the Atlantic. Though the energy of these winds is not the same as that of those in the Atlantic, they have an even greater steadfastness. This marvellous regularity of their movements was a delightful surprise to the early navigators. Varenius, exaggerating the truth somewhat, declares that on arriving at Acapulco, on the west coast of South America, the helm of the ship might be lashed and the sailors go to sleep, and they might still make their port in the Philippines, on the western side of that ocean. "The Spaniards called the trade-wind region 'El golfo de las damas,' for when once it was reached a girl might take the helm." *

* R. H. Scott: "Elementary Meteorology," p. 244. London, 1885.

It is evident that this distribution of the aerial currents is a permanent feature on the surface of the globe. The earliest navigators of the oceans found the constant and the variable areas exactly where we find them to-day. The ships of Columbus were borne westward by the northern belt of trades, and every sailor who since that day has traversed the field has availed himself of their movement. These gentle breezes are among the most steadfast features of the earth; they are older than the continents; they have indeed endured from the time when our geological records began to be written in the rocks. The primal cause of these constant winds, as well as of all the atmospheric movements of importance, is to be found in the unequal distribution of the sun's heat upon the earth's surface. If the earth presented, as men first imagined it did, a plane surface to the sun, there would be no such system of constant winds as we have indicated, for the reason that the heat would be equally distributed, and there would thus be a want of the disturbing causes which set the air into these more ordered movements. But the spherical shape of the earth causes the sun's heat to fall in very different share on the equatorial region and on the districts about the poles. Within the tropics, where the sun is from time to time vertical, and at most departs but slightly from that position during the course of the year, far more heat falls upon the earth than comes to the surface within the polar circles. This greater amount of heat received within the tropical belt of land and sea warms by radiation the layers of atmosphere near the surface of the earth; the heated air expands, and is lightened by its expansion to a greater degree than is the air of regions nearer the poles. It was at first thought that this heat directly produced an up-draught from the tropical regions, and that the air which becomes the trade-

winds flowed in from the north and south to fill the partial vacuum. Although this direct method of operating may in a measure account for the rush of the trade-winds toward the equator, it is by no means a sufficient explanation of the phenomenon.

We can best get a clear idea of the machinery of the winds by a simple illustration. Let us conceive a tall chimney, such as is frequently erected about manufacturing establishments where it is desired to produce a strong up-draught. For convenience, let us imagine that this chimney is closed at the top when we begin to heat a column of air within it which previously was at the temperature of the surrounding atmosphere. As soon as we have applied heat at the base of the column, it is evident that the air tends to rush upward in the shaft and brings an increase of pressure upon the summit. This pressure is due to the fact that the external air between the chimney-top and its base weighs more than the air within the chimney in its heated state. If now we remove the cap from the chimney, the air within this shaft will escape from the top; and if there be no wind, will flow off on every side over the surface of the colder air. Another familiar illustration may aid the reader to clear his mind as to the nature of this action. Let him imagine a trough-shaped vessel divided into three compartments, those at either end filled with water and the central space with oil, which, as he will remember, is slightly lighter than the water. If now we remove the barriers which separate the oil from the water, on either side, we shall see, as the eye clearly notes, that the water slips under the oil and the oil over the water. It is not necessary to try the experiment in order that it may be well conceived in that laboratory, the mind's eye. We have now only

to suppose that by some process the oil should become water as it flowed toward either end of the vessel, and the water to become oil as it approached the central part, to construct a convenient image of the process by which the air rises over the equatorial belt, and so leads to a current toward the equator, along the surface of the earth, and toward the poles in the higher atmosphere. Assuming that the reader now conceives how this primal difference in heat brings about the movement from high altitudes to low, along the earth's surface, and from low altitudes to high, in regions considerably above the earth, we may advance one step further in our considerations.

The next puzzling feature in the movement of the permanent winds is found in the fact that these currents do not move on north and south lines, as we should at first sight expect them to do, but the southward-moving winds, or those which in the northern hemisphere seek the equator, blow from the points between the east and north; while the upper currents, which convey the air back from the equator to high altitudes, move in the reverse direction, or from southwest to northeast. Although, as before remarked, our information concerning this upper air-current is limited, its constancy, swiftness, and general course are sufficiently proved by observations made on the summit of high mountains within the trade-wind belt, as well as by the movements of clouds in the principal regions of the atmosphere.

As long ago as 1735 an attempt was made to explain the origin of this deflection of the winds from the true north and south course. Although the explanation does not give a full account of the phenomenon, it still retains a place in the most of our text-books. We owe this account of the trade-wind movement to George Hadley. His explanation rests on the

fact that when a particle of air or of water, or any other matter, moves from the poles toward the equator, or from higher to lower latitudes, it is constantly proceeding into regions having higher rates of movement, by virtue of the earth's rotation, than those from which it came, and so, by virtue of its inertia, it constantly falls away to the westward. The earth in its rotation slips to a certain extent beneath it. In the reverse way, a particle starting from the equator, where it moves, by virtue of the earth's rotation, at the rate of a thousand miles an hour in an eastward direction, and proceeding toward the poles, where it will not have any translatory motion on account of the revolution of the earth, is constantly coming into regions having a less eastward movement than it at the moment possesses, and so outruns the movement of the earth, inclining in an eastward direction.

The reader can again illustrate this principle by an experiment, which he may try in practice, or essay in his imagination, by endeavoring to walk from the centre of a railway turn-table, such as is used for reversing the position of locomotives, to the periphery of that disk. He will conceive, or by an experiment he will have it proved to him, that he cannot walk on a straight line from the centre to the circumference when the disk is turning, but will attain a point on the periphery behind the point at which a radius of the circle intersects that line. Standing a moment on the periphery, so that his body may acquire the rotative movement of the disk, he will see that in walking toward the centre he again inclines to one side, because the momentum of his body makes it difficult for him to acquire the movement of the surface to which his successive steps bring him. When, however, we endeavor to apply the truth which Hadley dis-

covered to the spherical surface of the earth, we find it insufficient to account for the deflection of moving bodies on that surface. Pendulum experiments of the distinguished Foucault, made in the middle of this century, showed that, while Hadley's considerations were true, another principle is involved in the movement of the winds and of the ocean-currents. This principle is that, owing to the fact that the earth rotates from west to east, all bodies moving freely upon its surface will deflect on one direction, the measure of the deflection being due to the latitude of the point and the velocity of the moving particles. It is so difficult to give a popular explanation of this principle, and its comprehension is so far unnecessary to our aim here, that we may fairly ask the reader to accept this statement, or to look elsewhere for a detailed explanation.

It is worth the reader's while to conceive, as well as he may, the general principles which control the movements of the constant winds, for upon these movements, in a great measure, depends the whole system by which heat is distributed over the surface of the earth. This distribution is one of the many conditions on which the habitability of the globe absolutely depends. If the heat which comes upon the earth's surface from the sun stayed where it fell, if there were no machinery compensating for the irregularities arising from the excessive supply which falls in the tropics and the scant measure given to high latitudes, the equatorial region would be too hot for life, and the regions beyond the parallels of forty degrees north and south of the equator would be too cold; they would be locked in eternal frost. This compensation, it is true, is only in a small measure effected by the winds themselves; for, although they represent the move-

ment of a great body of air to and from the equatorial belt, this air has very little heat-storing power, owing to its gaseous elements. The work of compensation is accomplished in the main by the ocean-currents which the winds induce. The trade-winds, moving the surface-waters over which they rub, drive along a broad sheet of the ocean's surface from either atmosphere toward the equator. If these winds moved *squarely* down upon the equator, the result would be that the waters would soon be heaped up under that line, and the currents of the water would cease to flow; but as they move obliquely from the northeast and from the southeast toward the equatorial belt, they produce at their junction a wide westerly-setting current which flows at the rate of two or three miles an hour. When this current comes against the shoals of a continent, as it does against South America, it divides and turns in two streams toward either pole. In the case of the Gulf Stream the great equatorial tide sweeps on toward the northern seas, bearing with it a great store of tropical heat. To it Europe owes its habitability, and the region within the arctic circle receives from it more heat, as Dr. James Croll has shown, than comes to it from the direct rays of the sun. We see by this instance, one of many which could be adduced, that the atmosphere not only gives the primal conditions of life, but by its great movements secures to the larger part of the land and sea temperatures suited to the existence of that life.

Not only do we owe to the ocean streams the present fitness of the greater land areas for the uses of organic life, but during periods in the past history of the earth of which we have no record written in the rocks, during a time which certainly cannot be reckoned at less than 100,000,000 years,

the sea-currents have been doing this same beneficent work of taking excessive heat from tropical regions to warm the fields of sea and land, which, owing to their high latitudes, would otherwise have an extremely low temperature. The trade-winds and the ocean-currents, which in good part if not altogether are due to these great movements of the air, are among the most permanent features in the physical machinery of our earth. The trade-winds have doubtless blown, and the ocean-currents streamed away through the seas, since the dawn of geological history. From the most ancient times lands have existed which served to divert the streams of ocean water from the tropical belt to high latitudes. Thus, in the early history of North America, we can, from the evidence of coral reefs, perceive that in the lower Silurian, upper Silurian, and Devonian ages the vast tide of what we now term the Gulf Stream flowed up through a great arm of the sea which long occupied the Mississippi valley, and made its way by that passage toward the arctic circle, bringing a tide of warmth and life to the high latitudes of the northern hemisphere. Though much changed in position, diminished perhaps at times in volume, perhaps at times altogether diverted from the northern hemisphere, this stream has flowed on through all the æons of geological time.

We now turn to the second great group of atmospheric currents, those which constitute the inconstant winds. This group of air-currents affords a larger and more puzzling class of movements, more puzzling because they depend upon the interaction of many variable conditions. As to them all we may make the same general statement which we have already made concerning the constant winds, viz.: That they are primarily due to the excess of temperature in the lower

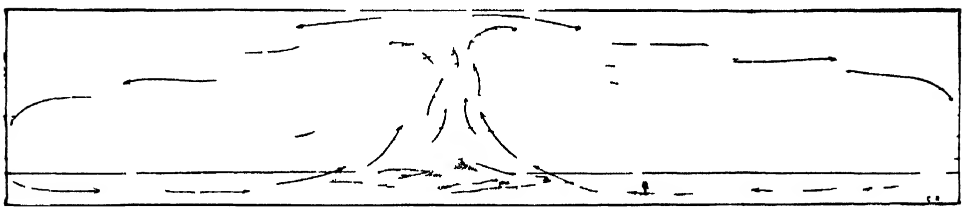
regions of the atmosphere, caused by the fact that the incurrent heat from the sun passes more readily through the air than the radiant heat does. Starting from this general principle, we find that the inconstant winds fall naturally into two categories: First, those which are caused by the difference in the condition of the air over the land and over the sea; second, disturbances which are due to a violent movement of the heated air which lies upon the earth's surface to escape into the upper regions of the atmosphere, whereunto its lightness, due to the heat it has acquired from the surface, makes it tend. The first of these two groups of inconstant winds affords us the class of what are commonly termed land- and sea-breezes, the effects of which, though interesting, are of relatively small importance in the economy of the world.

The simplest case arising from the difference in the condition of the air over land and ocean may be noted where a considerable island rises from a space of tropical open seas. A brief experience on such an island shows us that in the afternoon of each day a wind sets in from the sea and dies away about sunset. For a while the air is still, but toward midnight a steadfast current sets in from the other direction, namely, from the land, and blows until after sunrise. Thus the normal atmospheric conditions of the island give us alternating breezes enduring for about equal times, but moving in opposite directions. Here again we have to correct the usual statement as to the origin of these winds. It is generally said that the air, becoming heated over the surface of the land as that surface gains in temperature toward noonday, rises and so draws in the air from the sea, while at night the reverse action takes place. This theory is disproved by the

circumstance pointed out two centuries ago by Dampier, that the sea-breeze begins in the offing and extends gradually to the coast, while the land-breeze comes off from the shore and forces its way out to sea. Dampier's statements about the sea-breeze are: "It comes in an even, small black curl upon the water, whereas all the sea between it and the shore not reached by it is smooth and even as glass in comparison. In an hour's time after it reaches the shore it fans pretty briskly, and so increases gradually until twelve o'clock; then it is commonly strongest and lasts until two or three, a very brisk gale!" * Although the difference in temperature in the surfaces of the land and sea is the important cause of these changing currents, the method of action is probably not that just stated, but comes about as follows: The air from the surface of the land, being expanded by heat, is raised more or less above the surface, so that the levels of equal barometric pressure are higher over the island than they are over the sea, as is indicated in the diagram. This difference in elevation of the levels of equal barometric pressure causes the air to slide off from over the surface of the island to the portion of the atmosphere above the surface of the sea, thus increasing the pressure at the last-named points. This pressure directly forces the sea air in toward the island. Gradually, after the sun goes down, the land-surface cools until its temperature is below that of the sea, when the foregoing process is reversed. The lines representing equal barometric pressure over the land come nearer together; the air then flows in from the upper regions of the ocean atmosphere, weights the column of air, and forces the current out along the surface to the seaward.

* R. H. Scott: "Elementary Meteorology," p. 286.

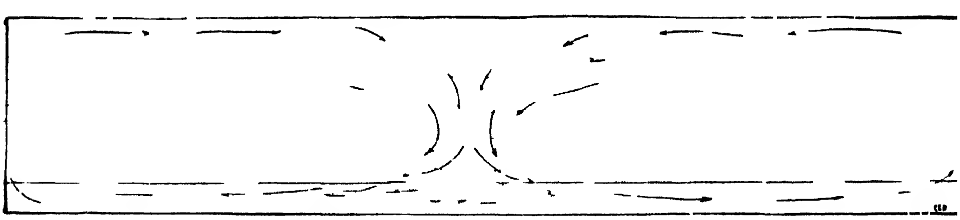
Along the margin of the continents we frequently find indications of land- and sea-breezes, which, although much more perturbed than in the case of oceanic islands, are still clearly due to the operation of the same forces. The east wind which, in the season of hot but still-aired summer days, creeps



Land and Sea Breezes No 1 Currents of Air by Day

[In this diagram as in No 2 the dotted lines represent like temperatures]

in upon the shore of New England and other parts of this continent, is an instance of this action. In the months of May and June the sea-water off the New England coast is often as much as thirty or forty degrees cooler than the surface of the land, and the air over these surfaces for a considerable height above the sea differs nearly as much in its temperature. Whenever there is no wind from the continent this air from the sea flows in beneath that on the



Land and Sea Breezes No 2 Currents of Air by Night

land, sometimes with considerable speed. It is interesting to watch the process of this movement, as it may frequently be observed along these shores, for it is the type of many of the aerial movements which are not so observable. Selecting a still summer day, and a point on the shore at the sea-level,

we may await the coming of the aerial tide. It approaches the shore in the form of a wedge, which slips under the heated air of the land. At first the thin point of this wedge may be only a foot or two deep, and has only a very slight motion, as may be shown by the smoke of burning paper, or even by the effect of temperature on the hand when it is held near the ground. The cold air gradually becomes deeper, but for an hour it may, in some cases, not be fifty feet in depth; so that on the lower floor of a tall house we may find the cool air creeping in from the sea, and on the upper story we may note a reverse movement of the warm air from the land seaward.

A Wh rlw rd

We have now considered those movements of the air which are more or less constant or regular in their action. We therefore turn to the group of irregularly variable winds. It is characteristic of these winds that they are temporary in their nature, often very violent, therefore not to be predicted, as are the constant movements of the atmosphere. Like the preceding class, they are due to differences of temperature of the air upon the surface, and in higher levels of the atmosphere brought about by the action of solar heat. They may, for convenience, be divided into three distinct groups, which receive, respectively, the names of whirlwinds, tornadoes, and cyclones. All three of these classes of inconstant winds are found both on sea and on land, but the two latter are

much more common on the land-surfaces, or on the portions of the ocean near the shore, than in the open sea. All these groups of winds have certain common characteristics which indicate a likeness in the circumstances of their origin. They all exhibit a more or less distinct spiral motion in the air involved in their movements; they all show a distinct ascending movement of the air in their central parts. In all of them this central part, the shaft of the whirl, has a more or less forward motion, and in the larger whirls the direction of this motion is tolerably regular in each region where they occur.

The common cause of this whirling movement is the existence of a heated layer of air next the surface of the earth, which air, by virtue of its greater heat, tends to be more expanded, and therefore lighter, than the overlying cooler mass of atmosphere. With certain trifling exceptions, to be noted further on, the heat of this sheet of air next the surface of the earth is due to the fact that the direct rays of the sun pass more easily through the atmosphere than do those of the rebounding or radiant heat which flows from the earth's surface outward into space. The result is that the ground, becoming more heated than the overlying air, gives out its heat to the layer of the atmosphere just above its level, and so creates a heated stratum which, on account of its gain in temperature, seeks to find a way upward. For a time, if there be no wind, this buoyant air may be shut in by the layer of cooler air which overlies it, and through which it finds no open path; but as the sheet grows thicker it finally, by some chance, makes a way through the stratum which holds it down and escapes to the upper regions of the atmosphere, to which its buoyancy impels it. A little experiment

will show the essential principles of this movement in substances which are more visible than these sheets of air, and on a scale more readily comprehensible. Placing a layer of oil on the surface of a flat vessel, it is possible, with great care, to float a sheet of water over it so that the superimposed water is of considerable thickness. We now have a lighter fluid below and a heavier above. This is an unstable condition, which naturally ends in upsetting the two fluids—a restoration of stability. As long as the overlying water is perfectly still, the tendency of the oil to rise may not cause any movement; but the slightest disturbance will determine the oil to break through the overlying water. If we pass a straw through the water and make a little stir in the two fluids, at once through the little gap a stream of oil sets upward. From all sides this oil slips to the path which we have formed, and in a few seconds the passage is accomplished and a stable equilibrium established.*

With this experiment in mind, let us proceed to examine any level surface, on a hot afternoon when the air is very still. It is necessary for the observation that it be made on some tolerably plain surface which is not covered with vegetation, for the leaves of plants radiate the heat which comes to them from the sun with great rapidity, and therefore the surface of

* This experiment can be more readily performed by choosing some oil which becomes partly solid at a temperature above the freezing-point, as, for instance, lard-oil. Warming the oil until it is transparent, we pour it into a flat-bottomed vessel, which must be warm enough to permit the oil to flow freely; then placing the vessel in another of cold water, we permit the oil to stiffen. Now pour in the water, place the receptacle in another basin of water, and warm gradually to melt the oil; then, as before, making a little stir, we determine the point at which the oil will rise through the superincumbent water, or we may wait for some slight jar to create the local disturbance, which will bring about the same result.

the earth beneath them does not attain the high temperature which we find it to have in regions without verdure. Let us note that the air next the surface of the earth is vibrating with the heat, so that if we stoop down and look through the air, within a foot or two from the ground, we see that the shape of all objects dances and twinkles in the mirage which is produced by the boiling motion which the radiant heat produces. With a thermometer we may note that there is a difference of many degrees between the temperature at the surface of the earth and at the height of a few feet above it. The difference is so great that it often can be perceived by holding the hand, first at six inches from the ground, and again above the head.

Beginning at sunrise on a day of unbroken calm, this process of heating the air next the ground goes on until afternoon; the tension then becomes so great that the hot air because of its lightness breaks through the cold. The place where the weak spot in the overlying layer of cold air is found is determined by various accidents. Some heated tree-trunk or tall object of any kind, rising a little way through the cold layer, may at that point make the hot air thicker than elsewhere, and consequently the strain upward at this particular place will be greater. As soon as this bottom air finds a way upward it swiftly rushes toward the point of escape, as is shown in the cuts. Immediately after the up-rush begins, the air streams in from every side toward the chimney, at first slowly; then, as it gains velocity, more and more swiftly. As it gets toward the centre its velocity is accelerated, and the particles of air crowd against each other. As soon as the upward movement is established, we find that the particles of the atmosphere take on the whirling movement. It is not so easy to explain the cause of this whirling as it is to show the

other circumstances of these centre-seeking currents, but we can easily note the fact that such movements occur in all cases where a fluid or a gas streams rapidly from a wide field through a small opening. Movements of this sort can be seen in a bath-tub where there is a hole in the bottom for the escape of the water. Filling the basin with water and lifting the plug, we see in a moment that the fluid begins to spin round as it flows to the centre. At first this whirling movement is along the bottom of the vessel only, but it is rapidly propagated upward until for the whole depth the water spins in the part next from the opening with such velocity that a conical hole is formed on the surface, which may extend downward to the outlet, and even for a little distance into the pipe which takes the water away.* Stirring the water with a motion of the hand, we can destroy this whirl, but it is quickly recreated. By giving the water a decided movement we can reverse the direction of the whirl, but in no way can we cause the water to escape without the rotatory motion. We thus see that, although the spiral movement is essential, the

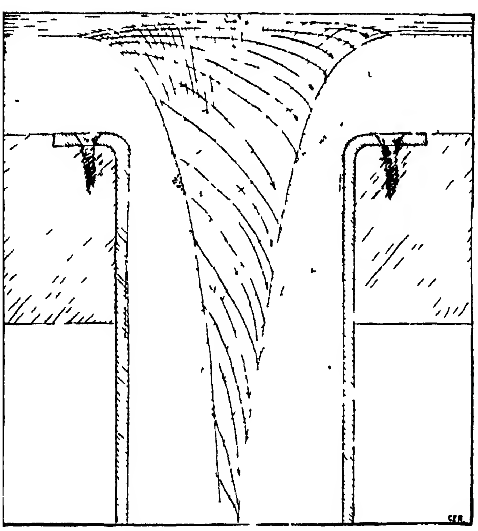
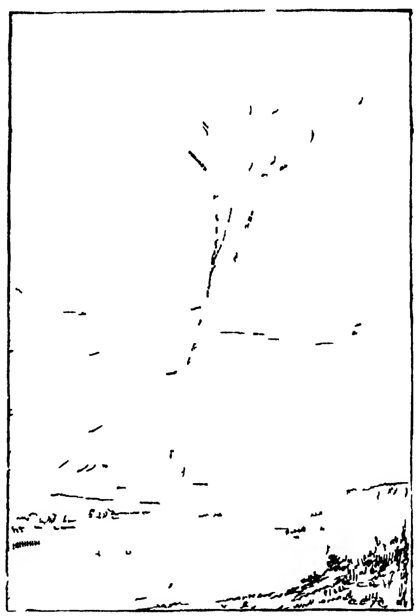


Diagram of a Sink Spout

* It is important in this experiment that the exit opening shall be unobstructed. In most cases modern bath-tubs and wash-basins have partitions across the space, which divides the turning water into several streams. Each of these streams creates its own little whirl, but they react against each other in such a way that no considerable whirlpool is formed.

direction, whether to the right or to the left, is a matter determined by circumstances.

The cause of this whirling movement, as far as it can be briefly and simply stated, is as follows: When the particles of air or water begin to rush toward the centre, the chance is infinitely great that they will not all follow straight lines leading directly to the middle of the column. Now, if any of them fail to go on the straightest lines, they will have to curve at the end of their course in order to join the upward march. They thus give a shove to one side of the delicately poised column, and so set it spinning round. As soon as the column begins to turn, fewer of the particles can move straightforwardly to the centre, and more press toward the side from which the column is turning and add their shove to the force which spins it. When it acquires a rapid movement, all the particles press on the same side, and so increase the velocity of its rotation.

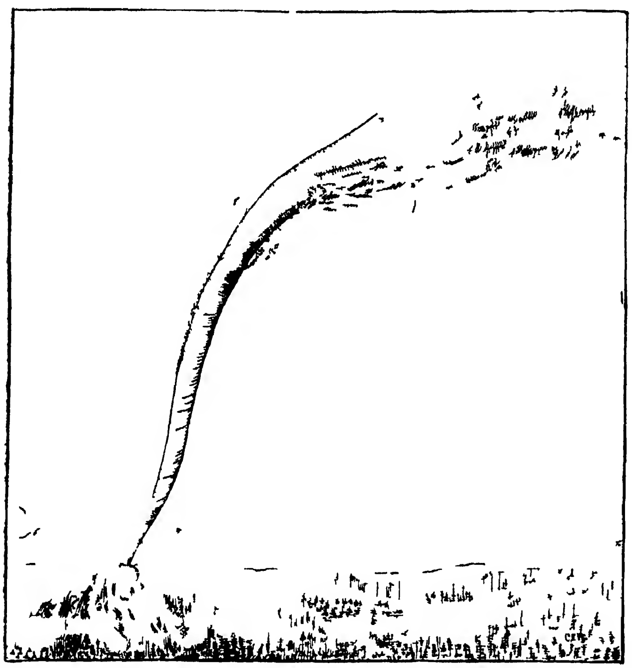


A Dust wh rl

Returning now to the whirl of the air—the dust-whirl, as we shall for convenience term it—we perceive that on the surface of the earth there is a broad disk, a few feet in depth and, perhaps, a score or two in diameter, through which the air moves toward a relatively slender vertical shaft. If the column be very distinctly developed, and the dust it draws up large in quantity, we may be able to perceive that at a few

hundred feet above the surface the cylinder expands into a form substantially like that which it had on the surface. In other words, the dust-whirl has an hour-glass shape, but the tube which connects the upper and lower cones is relatively very long.

Whirlwinds may be formed by the heat of the earth's surface, which is not derived from the rays of the sun, but from terrestrial sources of temperature. They are extremely common over forest-fires, where the air lying upon a district of hundreds of acres in extent is much heated; the heated air seeking to break through the cooler air above, exactly as in the case of the dust-whirl, takes the form of a spinning column. Even in a large burning building, careful watching will frequently show these whirls in the air above it. In volcanic eruptions they are also not uncommon; and on account of the intense heat arising from the emanations of the crater they are far more powerful than are dust-whirls or those developed by ordinary fires. Some years ago I had an opportunity of seeing a considerable forest fire in Bristol County, Mass. The burning area sent up a column having the form shown in



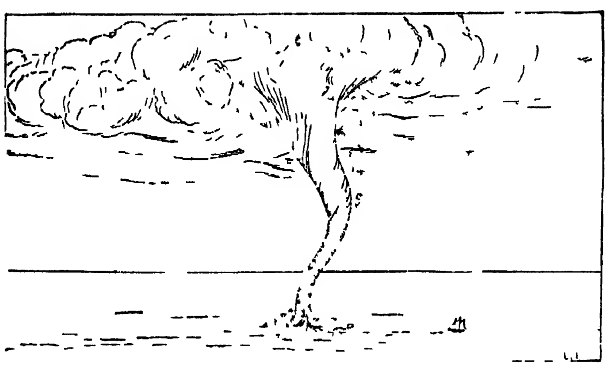
Smoke wh rl from Forest F re

the figure, which rose in the still air to the height of 2,000 feet or more above the surface. The engraving is reproduced from a sketch made at the time. The column was very distinct, piercing the still heated air of an August day to the height of a thousand or more feet with slight deflection from the vertical. Attaining the clear upper level, the smoke and vapor of water became diffused, forming an irregular mass of nimbus cloud, from which a slight fall of rain took place, the drops appearing to be evaporated in the lower air before attaining the surface of the earth. We have in this instance a fair illustration of the principle of the whirlwind, and also a small instance of the accidents which are to be described in the next paragraph.

The whirlwinds which attended the great eruption of Sumbawa, an island in the East Indies, in 1815, destroyed great areas of forests and drew up into the air the bodies of men and beasts, adding another source of havoc to that dire catastrophe. Where these whirls are formed over the heated surface of the sea they are often much more vigorous than the similar movements on the surface of the continental lands, for the reason that the air over the sea often remains for a long time calmer than over the land-surfaces. The greater energy of these whirlwinds over the surface of the sea may also be in part due to the moister nature of the air above that surface, which brings about an upward impulse in the column —in a manner to be noted hereafter. Where strong whirlwinds occur over the surface of the sea they produce the phenomena called *water-spouts*. The common notion that these marine whirlwinds suck up water from the sea to the clouds is almost certainly an error. It is true that the water leaps to the height of a few feet above the surface just

beneath the central part of the column, but the cylinder of cloud is due to the rapid condensation of the moisture in the air which is drawn up through its centre—condensation produced by the cooling which the air receives as soon as it escapes from the thin, heated lower layer. As we shall shortly see, the prairie tornado has the same general aspect as the water-spout, though there is no sea below it from which it can draw its water.

The passage from the sand-whirls of the streets and other desert places to the tornadoes such as ravage the central part of this country appears at first sight to be gradual; yet, as we shall see, though both depend upon the up-rush of the warm air through the colder overlying mass, the conditions which produced the warmth, and thereby give rise to the current, are not exactly the same. The smaller dust-whirls occur everywhere in the world; tornadoes are limited to particular regions, and those of disastrous violence occur only in certain limited parts of the earth's surface. One of their seats of most energetic development is in the central and western parts of the Mississippi valley. They are peculiarly frequent in the sections from Western Ohio to Colorado, though they occur occasionally in about all the level portions of the central trough of the continent, and also on the Atlantic slope. They happen most frequently in the months of May, June,



A Water spout

and July, but they occasionally occur at other seasons; indeed, they have been observed in every month in the year. They are commonest in the afternoons, but have been observed at other times in the day.

The way in which these tornado-whirls are formed differs in certain essential particulars from the way in which whirlwinds are created, as has been well shown by Professor Ferrel. The most important points of difference are as follows: The dust-whirls are due to the heating of a thin layer of air next the ground. The small mass of this layer prevents its upward whirling from bringing about any powerful movements of the atmosphere. In the tornado the heat of the lower air has a different origin. When a cyclone passes over the surface of a country, certain peculiar movements of the atmosphere which it produces bring large volumes of the warm and moistened air to the earth's surface and overlay them by a cool stratum. It is not necessary for us to describe the exact process by which this condition is brought about; it depends upon rather complicated reactions which take place within the cyclonic whirl. It is sufficient for our purpose to note that in this manner a deep layer of warm air is placed next the surface of the earth, and that it does not

Soct on through a Tornado

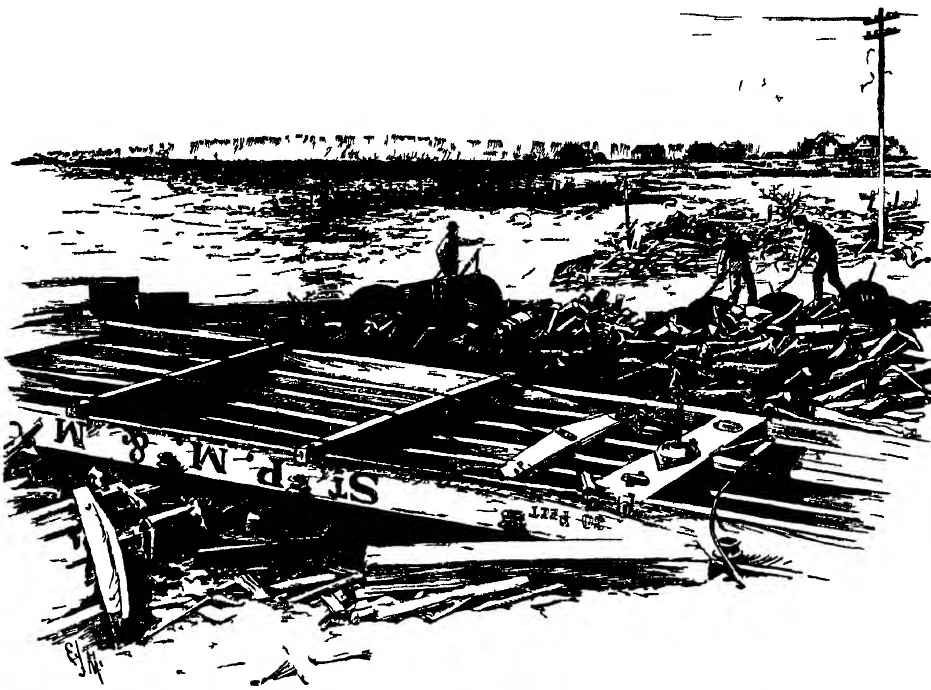
owe its temperature in any immediate way to the heat which radiates from the earth's surface. This layer of warm, moist air tends to rise up for the same reason that the thin layer of dry air which forms the dust-whirl is impelled upward, but on account of its great mass the intensity of the upward urgence is far greater.

In the sand-whirl the upward motion begins close to the earth's surface for the reason that the stratum which is impelled upward is very thin, but in the tornado the stratum of heated air is usually about a thousand feet thick; therefore its whirling action naturally originates at the upper surface of the hot layer, for it is at that point the upward motion begins. Starting in this upper region, the whirl extends progressively downward, just as in the bath-tub the whirl extends progressively upward from the point at which the motion originated, until the whirl may touch the surface of the earth. When these whirls begin they only involve a small part of the air about the point of origin, and so the acquired velocity of the particles when they come to the centre is not great; but gradually they suck air from farther and farther away. As the field of supply becomes larger, and the particles move from a greater distance, they approach that centre with greater and greater speed, and the spiral widens and turns with accelerated velocity. The longer the journey of the particle, the swifter its whirling motion becomes. We may secure a familiar and fairly good illustration of this motion by whirling a weight on a string and at the same time allowing the string to coil around the finger, thus constantly shortening the length of the circuit the weight traverses. We thus observe that the speed of the motion sensibly increases as the line shortens.

When the particles of air start from a mile away toward the centre of the whirl, they may move at the rate of a gentle breeze ; when they have come to within a hundred feet of the centre, the motion may have the speed of a hurricane. The more nearly the particle of air approaches, the stronger the centrifugal force becomes, and the air pulls away from the centre just as does the weight attached to the string when it is coiled nearly to the finger. The result is a partial vacuum in the centre of the tornado-shaft which seeks to be filled. It must fill itself from either end of the cavity. It cannot draw air from above, for the reason that there the atmosphere is so much lighter that it will not descend, but on the surface of the ground there is air which, though whirling, is not moving with anything like the speed that it has in the higher part of the shaft, for the following reasons : In the first place, the whirl begins high up and extends gradually downward toward the earth's surface, therefore the air next the ground, being the last to be set in motion, has not acquired the speed of that in the upper portions of the column ; furthermore, the air upon the surface is hindered in its movements by the great friction which the irregularities of the earth exert upon it—this friction in a tornado, as in an ordinary gale, reducing the rate of the motion in a surprising manner. The reader may readily observe this effect by noting the speed with which the scud of a storm flying at perhaps a thousand feet above the surface moves. He will often find a motion of fifty miles an hour or more indicated by this scud, while on the surface of the earth the speed of the gale does not exceed half that amount. This difference represents the effect of the earth's friction. The result is that this relatively quiet air next the ground is sucked into the tube with extreme rapidity, and mounts with much less

whirling movement than we find in what we may term walls of the whirl—that is, the rapidly circling particles which lie on either side of the partly vacant central portion of the column.

Curiously enough, the up-rushing air in the central shaft of the tornado obtains a certain access of heat from the upward motion of the atmosphere in the shaft. This gain of force is



Effect on a Train in the Centre of a Tornado From a photograph taken at Sauk Rapids Minn April 1886

brought about in the following manner: The warm air, the rush of which constitutes the tornado, contains a considerable amount of water in the form of vapor. This water is held in the vaporous form by the action of the heat, which pushes its molecules apart. As soon as anything causes this vapor to condense in the form of visible water, the force which pushed the molecules asunder again appears as heat, and, by expanding the air in which the condensation takes place, causes it to retain its ascending force for a greater time than it would

otherwise maintain it, and so intensifies and continues the uprushing movement of the column. In the ordinary tornado, owing to its relatively small size, and to the brief duration of its action, this force derived from the condensation-vapor has no very great influence on the violence of the movement; but, as we shall hereafter see, this peculiar effect of condensing vapor has a great importance in the cyclones, that last species of atmospheric whirls which we have yet to consider.

When the conditions of atmospheric instability have given birth to a tornado, the fact is announced to the observer by a sudden gathering of dark, swift-whirling clouds, from which depends a writhing, serpent-like body formed of condensed vapor. This writhing column extends rapidly downward until it touches the earth. When it attains the surface it becomes audible from the violent rending actions which it creates upon that surface. As soon as the whirl is created it begins to move away, generally toward the northeast,—for the evident reason that the upper cold layer of air against which it originates has, in the northern hemisphere, a movement in that direction.

In its path over the surface, the circling movement of the writhing air and the sucking action of the partial vacuum in the central portion of the shaft combine to bring about an extreme devastation. On the outside of the whirl the air, which rushes in a circling path toward the vortex, overturns all movable objects, and in the centre these objects, if they are not too heavy, are sucked up as by a great air-pump. Thus the roofs of houses, bodies of men and animals, may be lifted to great elevations, until they are tossed by the tumultuous movements beyond the limits of the ascending currents and fall back upon the earth. Where the centre of the whirlwind

passes over a building, the sudden decrease in the pressure of the outer air often causes the atmosphere which is contained within the walls suddenly to press against the sides of the structure, so that these sides are quickly driven outward as by a charge of gunpowder.

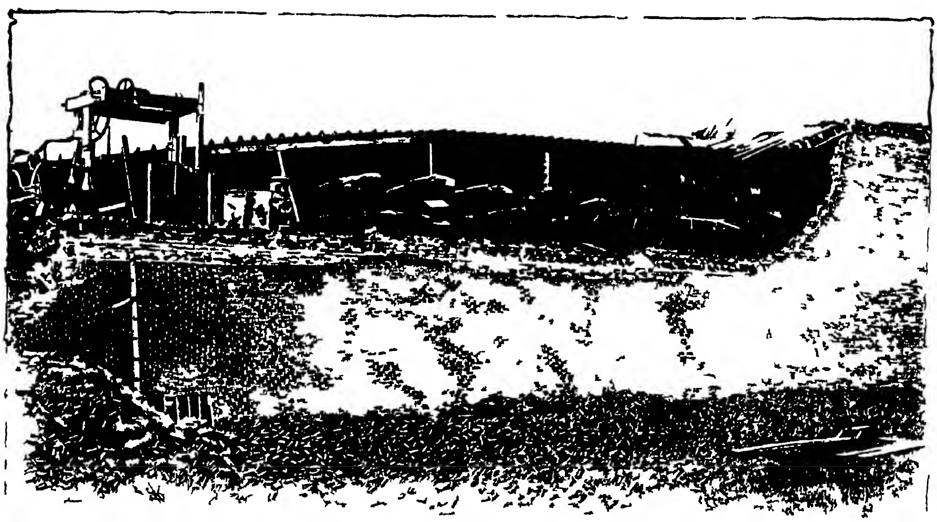
It is not unlikely that the diminution of pressure brought

Showing Explosive Effect of Air contained in the Hollow Wall of a Building. From a photograph taken at Rochester, Minn., August, 1883. [Note that the effect is limited to a small part of the edifice.]

about by the passage of the interior of the whirl over a building may be about as much as is indicated by the fall of four inches in the barometer. This is equivalent to a change in the pressure amounting to about three hundred pounds to the square foot. This force operates to burst out the walls of a building. It is not improbable that the diminution of pressure

may be much greater than this, but even the amount named is sufficient to account for the destruction of the frail-walled structures which these devastating movements encounter in the western parts of the United States.

Fortunately the paths of these tornadoes are ordinarily very narrow—the widest have a diameter of less than two miles; the narrowest of only forty feet. In most cases a tor-

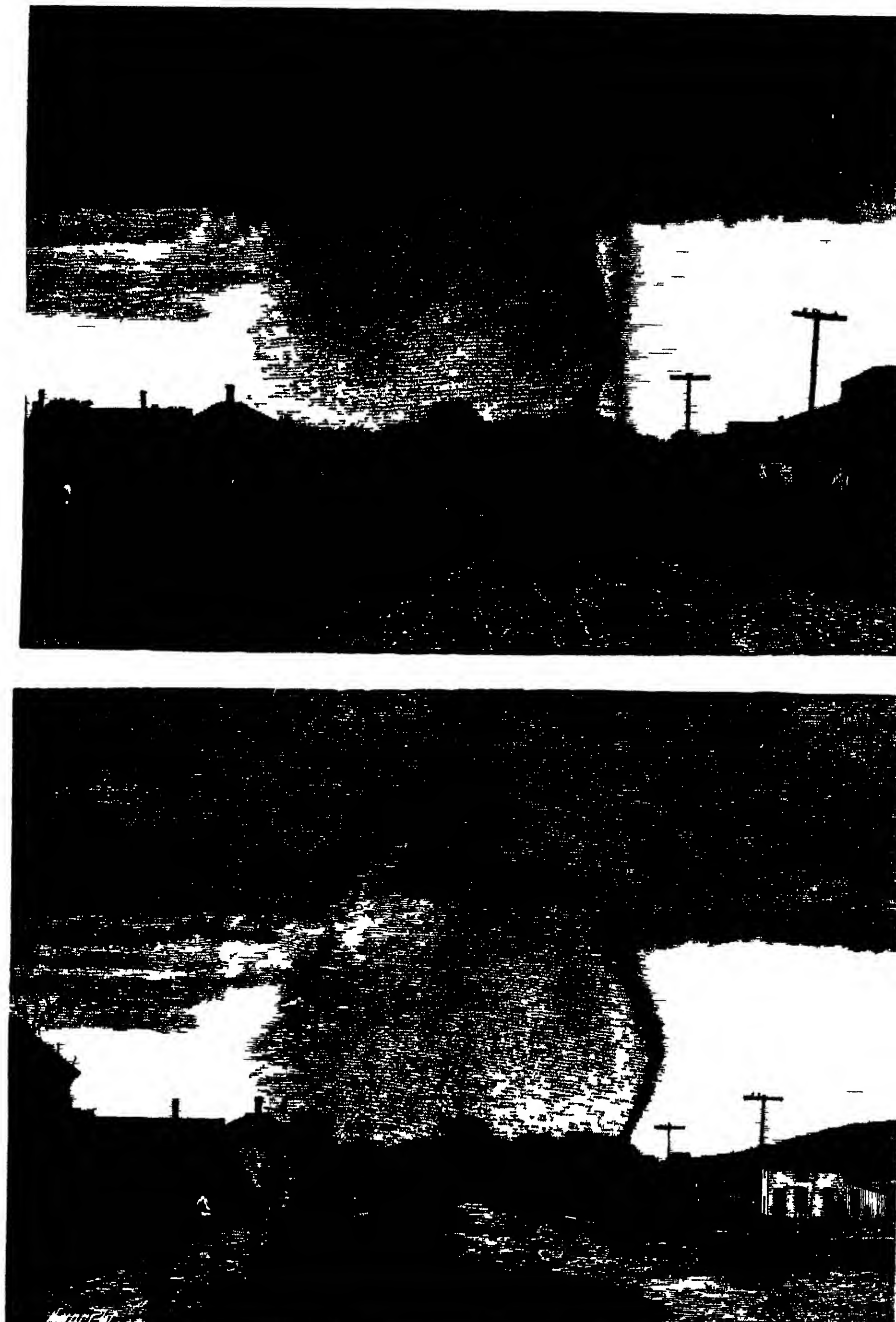


Showing the Narrow Limits of the Destruction and the Completeness of the Ruin within the Limited Field
From a photograph taken at Rochester, Minn., August, 1883

nado is seriously destructive over a width not exceeding five hundred feet. The length of the tornado's path across the country does not commonly exceed thirty miles, and it generally traverses the distance in about an hour. When the upward corkscrew motion of the outer part of the spiral and the swifter up-rush of the air through the central shaft have drained away the most of the warm air which gave birth to the motion, the tornado dies away. The equilibrium of the air-masses is for a time restored, the heavier air has fallen down upon the

surface, and the warm air, spreading laterally as it attains the level to which it tends, comes into a state of quiet. Assuming the width of the destruction brought about by the storm at six hundred feet, and the length of its journey at thirty miles, we find that the area of its devastation amounts to about two thousand acres, or to a square area about two miles on a side. Over this area the destruction is ordinarily more complete than that which occurs in the most severe earthquakes.*

* These tornadoes are, even in the present scattered condition of the population in the regions they afflict, a source of great destruction to life and property, and with the increase of population each year they are likely to produce even greater loss. The question arises, What can be done to mitigate these evils? It is evident that these devastations depend upon such great causes that we cannot hope in any manner to prevent their occurrence, but it seems possible in certain simple ways to limit the destruction they bring about. By far the greatest loss of life and property is caused by the frail nature of the structures—generally timber buildings of unsubstantial character—in which inhabitants of the tornado district dwell. These buildings, though well suited to resist the action of earthquakes, are utterly unfitted to oppose these convulsions of the air. A building intended to meet the tornado shock should, it seems to me, be constructed in the following manner: Where possible, it should possess thick masonry walls of stone or brick united by strong mortar. Masonry seems to be the preferable material, for the reason that the storm, owing to its rapid forward movement, acts on any one place having the area of a house for only a second or two; thus the inertia of the mass will serve to protect it from the ravage of the brief storm. If there are partition walls within the house, these partitions should be tied firmly to the outer walls by suitable bolts. There should be large windows in the cellars and in the house itself, which may be blown out with ease, and so afford egress to the expanding air. Roofs should be firmly tied to the outer and inner walls, and the attic space should be provided with windows which would similarly permit the egress of the air. The building should be of as little height as possible. There should be no external parts of the edifice which are not well secured to the main mass. Timber fences and other frail structures, which are easily torn to pieces by the storm, may supply debris with which the wind, by whirling about, may inflict damage. Such a house would be likely to survive the action of almost all the observed tornadoes. It would be well, however, for the occupants of even the best constructed houses in districts much afflicted by tornadoes to have a refuge-chamber constructed a little below the surface of the ground, immediately adjacent to the



Instantaneous Views of a Tornado

From photographs taken near Jamestown, Dak, June 6, 1887, by Mr C L Judd, while the column was eighteen miles distant and rapidly receding The upper picture represents the tornado at its fullest vigor, the lower, when it had begun to wane The centre is shown by the dark line of the funnel, behind which trails the storm of rain and hail which is a usual accompaniment In passing over a lake about two acres in area, this tornado sucked up all the water, leaving the ground "dry enough to be ploughed"

We have already noted the fact that these tornadoes are due to the presence of thick masses of warm and moist air next the surface of the earth which seeks a passage up through the superincumbent atmosphere. Recent discoveries have made it clear that these destructive whirlwinds lie within the field of certain greater whirls, known as cyclones, and that to the action of these vast revolving storms we owe the atmospheric conditions which lead to the tornadoes. The peculiar movement of these cyclones crowds great masses of warm air toward the southeastern portion of their border, which masses are

southwest side, and readily accessible from the interior as well as from the exterior of the dwelling, to which they may resort upon the approach of the danger. An underground chamber, eight feet square and six feet high, covered by three or four feet of earth, provided with one or two entrances of no more than sufficient size, without doors, would afford an absolutely safe refuge in the worst of these catastrophes.

The records of Western tornadoes show within the last ten years a loss of killed and wounded of between one and two thousand persons. By far the greater part of these accidents to life and limb might have been avoided if such provisions for refuge had existed. The loss of life from lightning in the same region has not been anything like as great, and yet almost every house has its provision of rods, which are much more costly than the storm-refuges which we have described, and are generally worthless for protection.

In the case of barns the part devoted to sheltering stock should be placed partly underground, and the portion above the surface should be banked up with earth as high as may be. The floor which parts the level of the stabling from the upper portion should be strongly secured to the lower walls. In this way the upper portion of the building may be abandoned to the chance of accident, while the part containing the beasts may be secure.

It is quite conceivable that something may be done by means of telegraphic communication to convey intelligence concerning the movements of these tornadoes, but the warning given by the roar of the movements upon the surface is, except in the rare cases where the catastrophe occurs in the night-time, sufficient, when taken with the long forewarning afforded by the aspect of the sky, to put people on their guard. The time is generally ample for men to return from the field and place themselves and their beasts in their respective shelters.

overrun by the cooler upper atmosphere, thus bringing about conditions which give birth to the tornado. It is readily seen that this discovery may make it possible for the meteorologist to predict, at least in a general way, the districts which are liable to tornadoes, but it is still far beyond his science to tell just where the blow will be struck.

There are many reasons why it is desirable to know something concerning the distribution of tornadoes in this country.

Showing the Overturning Action of a Tornado on Buildings From a photograph taken at St Cloud, Minn, April 15 1886

As yet a large part of the field subject to frequent cataclysms of this nature has been settled for such a short time that it is not possible to secure satisfactory data on which to found any statements concerning the frequency of their occurrence. The incomplete evidence, however, goes to show that nearly all of the region of the eastern United States, say from the one hundredth meridian eastward to the Atlantic, is more or less liable to visitations of this nature. It is evident, however, that in their frequency of occurrence, as well as in their intensity and the range of their destructive paths, they vary greatly in dif-

ferent parts of this great area. They are most frequent and most intense in the untimbered districts of the Mississippi valley north of the Red River. It may be that their relative fury in this field is due to the fact that the cyclonic storms which they attend are most frequent and well-developed in that section of the field. It is possible that the absence of timber may have something to do with producing the atmospheric tensions which lead to these catastrophes.

Tornadoes of much violence occasionally occur in Kentucky, Tennessee, and the northern portion of the Gulf States. A few such accidents have been recorded in the Atlantic States north of Virginia, but their more violent and frequent manifestations are practically limited to that part of the Mississippi valley which lies to the north of the Ohio River and the Red River. In that field, although the liability to tornadoes varies in different parts of its areas, it is safe to say that these accidents are probably ten times as frequent as in any other equal area on this continent.

In default of historic records, it seems possible to obtain some clew to the hurricane history of any region occupied by forests, by an inspection of the conditions of its woodlands. The hurricane tracks in the woods of the Mississippi valley remain evident from the fallen trees and the relative youth of the new-grown timber for more than a century after the occurrence of the storm. Even after several centuries the influence of the catastrophe may be indicated by the change in the character of the timber along the path of the storm. If in any woodland whatsoever a belt of timber is removed, either by the axe, by fire, or by tempest, the trees which succeed those which have been destroyed are generally of different species from those which have previously occupied the area.

This phenomenon of succession in forest trees is familiar to all those who are well informed concerning the histories of great areas of woods, and the facts enable us frequently to assert that at some time in the past, perhaps three or four centuries ago, a given tract of country has been swept by a tornado. At several points in Kentucky and in the neighboring States I have been able in this manner to determine the track of

Showing Grades of Destruction from Centre to Border of Tornado From a photograph taken at St Cloud, Minn April 15 1886

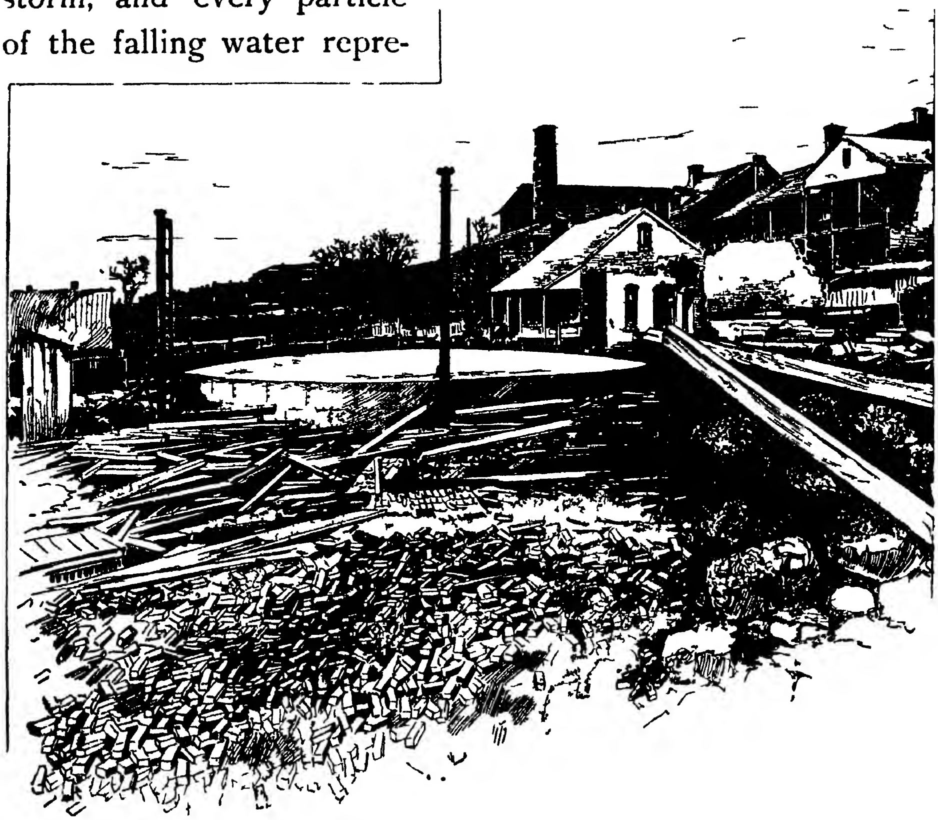
ancient hurricanes. My observations lead me to the conclusion that devastating accidents of this description are on the whole rare throughout the timbered districts of the Ohio valley.

In cyclones we find the largest manifestation of that energy by which the superheated lower air whirls upward from the earth through openings which it has rent in the higher cooler layers. In its fundamental cause the cyclone is essentially

like both the lesser classes of whirls, the dust-whirls and tornadoes, but the field of its work is vastly greater, though the energy which it exercises at any one point is less. The conditions which lead to the formation of a cyclone are probably as follows : In those heated portions of land and sea where the circumstances permit the air to remain for a long time undisturbed, it becomes very warm and charged with moisture ; the hotter it becomes the more moisture it contains, and the less it permits the heat radiating from the surface to pass through its texture ; at the same time the upper air, deprived of its usual share of radiant heat, becomes abnormally cold ; finally, as in the dust-whirls and tornadoes, the lower air breaks through the upper and rushes toward the sky. Although at its beginning a cyclonic storm is probably of no greater size and of much less ascending force than a tornado, there are several reasons which make its history different from that of the smaller whirls. In the first place, the field of heated air which causes the cyclone is far more extensive than that which produces the tornado, though at the same time the difference of temperature between the upper and lower air may be less. The greater bulk of the lower stratum of hot and moist air permits the cyclone to grow larger, but the less ascensional force of the lower air makes it rather less violent in its movements.

As soon as the ascending current brings a portion of the heated air from the surface into the higher level, it expands, and the force, originally in the form of heat, which kept it in the state of vapor, serves to increase the ascending column just as much as would the direct application of heat sufficient to vaporize the water. Thus we have two sources of force to impel the air in the cyclone upward. Both these forces, as we have already seen, appear in the tornado, but there the

original heat of the lower air is the principal cause of the motion. The heat arising from the condensation of vapor is of considerable moment in cyclones, especially those which occur over tropical seas. Torrential rains fall beneath the wide central shaft of the storm, and every particle of the falling water repre-



Showing Sharp Passage from the Centre to the Periphery of a Tornado From a photograph taken at St Charles Mo

sents the conversion of energy which held the fluid in the shape of vapor, into force which is added to the essential vigor of the up-rush of air. To this cause we may perhaps attribute, in part at least, the long life of these cyclones, and the great size to which their whirls attain. Unlike the tornadoes, they often continue in existence for many

days, have a width of several hundred miles, and sometimes pass over a course several thousand miles in length.

As in the case of the dust-whirl and the tornado, the ascending column of air, after attaining the height where it no longer tends to rise upward, spreads out over the surface of the sheet through which it has broken its way. When it has drained out all the air warm enough to rush upward the disturbance ceases. All these larger whirling movements of the air, whether they occur on land or sea, move forward in directions proper to the region in which they occur, at a more or less rapid rate,—in the cyclones these translatory movements of the storm being sometimes at the rate of fifty miles an hour. The principal cause determining the speed and direction of the movement is doubtless the course of flow of the great upper currents of the atmosphere, which, however perfect the calm of the surface, are always in motion in determined directions. This element of regularity in the movement of cyclones enables us to predict, in some regions with great certainty, the direction in which these whirls will move. Observations have also determined the regions where storms of this nature occur, and the seasons of the year when they may be expected. Science has gone still further, and shown the mariner how he may in most cases avoid the central portions of the storm-area, and so escape the dangers arising from the strongest winds.* The rotation of the earth so

* The following account of the rules for avoiding the storms is extracted from Professor W. M. Davis's Whirlwinds, Cyclones, and Tornadoes: "The storm's earliest effect on the atmosphere is shown by the barometer. It is ordinarily stated that the first effect is seen in a diminution of pressure; but it is very probable, both from theory and from careful observation, that a slight abnormal increase of pressure precedes this diminution. The tropical seas, where cyclones are most violent, have, as a rule, very small and very rare irregular changes in atmospheric pressure; and

affects the movement of these great spiral ascending currents that in the southern hemisphere they always spin in the direction in which the hands of a watch turn when it is held horizontally, with its face toward the eye, while in the northern hemisphere they move in the reverse direction. On this general basis, rules have been laid down for the direction of mariners when they find themselves in contact with these storms.

Recent studies on the phenomena of oceanic cyclones have served still further to aid the navigator by showing him something of the laws which control not only the movement within the great space of the circular storms, but also the path of the meteor over the surface of the sea. It is now believed that the first atmospheric condition which indicates the approach

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careful watching will pretty surely show a rising barometer, as the annulus of high pressure that surrounds the storm moves over the observer. The weather may still be clear, and the wind moderate and from its normal quarter; but this change in the glass demands renewed watchfulness. Let us suppose that such an observation be made on board a vessel lying east of the Lesser Antilles. The chart shows the captain that he is in the stormy belt. He may be directly in the path of the advancing storm, where he will feel its full violence; and he must make the best of his way out of it. Following the rising pressure, three other signs of increasing danger may be observed: First, faint streamers of high cirrus-clouds may be seen slowly advancing from the southeast to the northwest, or from the east to the west, in the high overflow from the storm's centre; this unpropitious change may accompany the rising of the barometer, or may be first seen when the barometer is highest. Second, the barometer begins to fall, slowly at first, but more and more quickly when it reaches and passes twenty-nine inches; the vessel is then within the limits of the storm. Third, the wind has shifted so as to blow from a distinctly northern quarter, and its strength goes on increasing; this is the indraught, blowing spirally toward the centre. There is then no longer any question that a storm is approaching; and as soon as a heavy bank of clouds makes itself seen, moving southward across the eastern horizon, then the central part of the storm is in sight. These clouds are the condensed vapor in the rising central spirals, and rain is falling from them. In deciding on a course to be pursued, the first point to be determined is, where is the

Showing Grades of Destruction from Centre to Periphery of Tornado. From a photograph taken at St. Cloud, Minn., April 15, 1886. [Note the relative immunity of the trees.]

of a hurricane is found in the cool, dry, brisk winds and a very transparent atmosphere, accompanied by a rather unusually high barometer. When with these conditions there is a long swell upon the sea proceeding from a point on the horizon where light streamers of cloud rise up, the mariner may, if the season be between the 1st of June and the 1st of November, and he is placed in the Atlantic north of the equator, be pretty sure that he is upon the periphery of such a great storm, though still perhaps at a distance where proper use of his wits may enable him to escape from it. He may safely assume that the storm has a width of from two hundred to five hundred miles, though the dangerous part of its area may not exceed the smaller of these figures. He may also assume that the rate of movement of the storm-centre—that is, its progress over the sea—is from twelve to twenty knots an hour,

storm's centre? That being known, its probable path can be laid down with considerable certainty in this part of the ocean; and then, perhaps, the greatest danger may be avoided. But here a very practical difficulty arises. To find the direction of the storm-centre, we must know the incurving angle of the wind's spiral—the angle of inward inclination that it makes with a circle whose centre is at the storm's centre. The earlier students of the question—Dove, Redfield, Reid, and Piddington—considered the course of winds to be concentric circles, or inward spirals of very gradual pitch; so that they said the inclination of the wind is practically zero, and a line at right angles to its course must be a radius leading to the centre. Later studies showed this to be incorrect. The inclination of the wind inward from the circle's tangent was found to vary from twenty degrees to forty degrees or fifty degrees, but it was thought that this inclination was symmetrical on all sides; so that, with an average inclination of thirty degrees, the storm's centre must always bear sixty degrees to the left of the wind's course. Finally, the most recent results seem to show that the wind's course is neither circular nor symmetrically spiral; that the wind's inclination is very distinctly different in different latitudes, on different sides of the storm, in the different conditions on sea and land, at different distances from the centre, and at different altitudes. In so complicated a case, much judgment will be required to find where the storm-centre lies."

at least in low latitudes, though it may attain a higher rate of translation as it moves farther away from the equator. The most important point is to determine the general path of the storm-centre. In low latitudes in the northern hemisphere, this centre apparently moves in all cases first west-

Overturned Train, showing Effects at Some Distance from the Centre of a Tornado From a photograph.

ward and then northwestward, and slowing in its rate of motion as it so turns. Finally, after describing this curious curve, it turns to the northeastward, attaining then the velocity of translation of twenty or thirty miles an hour, and at the same time increasing the width of the spiral but diminishing the energy of the wind movement. Having established

its northeast course, it may continue to move to the eastward until it attains the coast of Europe. Recent observations have also shown that the shape of the storm is not at once what was first supposed, circular, but is elliptical, the greatest diameter of the ellipse sometimes amounting in all to twice the least diameter. Although these newly ascertained points serve somewhat to complicate the duties of the shipmaster and to call for the exercise of greater discretion in meeting these dangers, they are manifestly a contribution to our knowledge which may diminish the perils of the sea.

Great as is the damage done by cyclones on the sea, they are to our modern well-constructed steamships no longer so fraught with ills as in the old times when vessels were altogether propelled by the air. Our steamers are rarely wrecked by them, for the reason that their motive power is independent of the winds. But when these great whirls approach the shores, especially where these shores are low-lying and populous, the destruction which they bring about is sometimes frightful. On the delta shores of the Bay of Bengal, where these cyclones not infrequently occur, the destruction of human life is very great. Since the year 1700 over half a million lives have been lost in these catastrophes. The principal part of the damage is brought about in the following way: When the storm-centre is over the land, the winds blowing toward that centre from the sea heap up the water against the shore. The rise of the ocean-surface along the shore-line is also favored by the low barometer which prevails there, and the relatively great atmospheric pressure on the periphery of the storm. These two causes tilt up the water next the shore and force the sea over the dikes, adding the destruction of floods to that brought about by the winds. Fortunately the

conditions where these unhappy accidents of flood are to be feared are rare.

On the continent of North America there is only one region where the floods produced by hurricanes are likely ever to prove a very serious danger to the people. The coasts of Florida, both its eastern and western shores, particularly the land from Key West northward to Indian River, are subject to great incursions of the sea during the time when hurricanes are moving across the peninsula toward the North Atlantic. The violence of the wind in this section, though its movement is at great speed, does not appear likely to endanger buildings of ordinary solidity; but the changes in the pressure of the barometer occurring during the passage of the storm, as well as the drift of the sea produced by the wind movement, serve to raise the ocean waters many feet above their usual level. I was informed that along the key-bordered coast of Florida between Key West and Key Biscayne, the sea has been known to rise during the passage of one of these storms to the height of ten or fifteen feet above its usual level. At present this coast region is essentially uninhabited, and the people are generally in position where they can secure refuge on elevated portions of the coral reef above the plane of the inundation. If, however, this region should ever become thickly peopled, the danger of catastrophic invasions of the sea in hurricane times would be about as great as along the shores of the Bay of Bengal.

The principal atmospheric disturbances of the United States usually have a more or less cyclonic character, but they are rarely such regular whirls as those which form on the ocean. The numerous storms which move eastward from the plains at the foot of the Rocky Mountains generally have

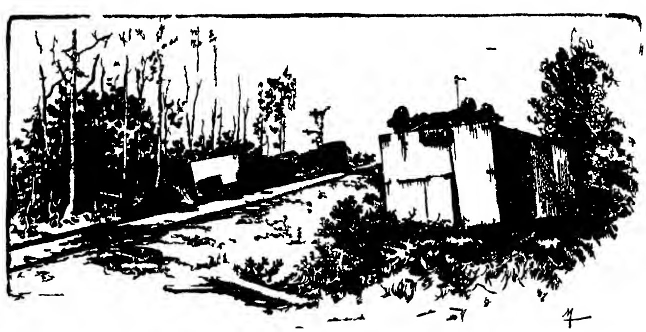
a distinct whirling motion, derived, perhaps, from an ascending movement. Still in many cases circumstances of their origin make it plain that they cannot be caused, as in the other type of marine cyclones, by the presence of relatively hot and moist air upon the surface. The causes which produce them have not been well determined. It seems likely that they have been originated in the Pacific Ocean, or are shaped by conditions derived from that little-known meteorological field. Although our Weather Bureau has given them much study, these great land whirls afford still a wide field for research.

As we go from the equator toward the north pole, the influence of the wide seas becomes less considerable, and the variety of conditions afforded by the crowded lands greater. The result is that the region about the north pole has storms which are more irregular than those which we find in lower latitudes.

The foregoing account of the perturbations of our atmosphere is altogether insufficient to give the reader more than a general account of their primary conditions. We perceive that in the main they are due to the action of the atmosphere in resisting the escape of radiant heat, whereby its lower parts become too much heated to remain on the surface. Although these disturbances are often destructive to life, they arise from the operation of a mechanism upon which the existence of all life depends. If the air did not thus retain the heat which comes from the sun, the earth's atmosphere would rest upon land and sea locked in eternal frost. As the earthquakes are movements of adjustment which attend the changes of the crust,—changes which preserve our lands

above the level of the ocean,—so these disturbances of the air are apparently inevitable actions arising from conditions which are essentially beneficent.*

* The reader who desires a sufficient and easily comprehensible account of these whirling movements cannot do better than read the excellent book by Professor Davis before referred to If he can use the higher mathematics he will find Professor W Ferrel s Recent Advances in Meteorology in the Annual Report of the Chief Signal Officer for 1885 Appendix 71 a complete discussion of the subject



Effect on a Train close to the Centre of a Tornado From a photograph taken at Grinnell Ia June 18 1882

FORESTS OF NORTH AMERICA.

Arboreal Ancestry of Man; Need of Destroying the Forests; Evil Effects of Deforesting; Relation of Forests to Soil; Protective Effects.—Origin of Forest Trees; Geologic Succession of Plants; Forests of Coal Measures; Evolution of the Form; Comparison of Broad and Narrow Leaved Trees.—Study of a Forest District; Purity of Forest Streams; Compared with those of Tilled Districts.—Soil of Forest.—Forest Sponge Effect on Rainfall; Instances from Appalachian Forests.—Variety of Trees in Forests of North America; Comparison with Europe; Advantages arising from this Variety.—Bald Cypress; its Knees.—Sour Gum; its Root Loops.—Willows.—Effect of Position on Trees.—Recovery of Land by Forests; in Southern States; in New England.—Comparative Vigor of Conifers and other Trees.—Effects of Glacial Period on Forests; Processes of Selection.—Origin of Prairies; Effect of Fires; Reforesting of Prairies.—Underground Work of Forests; Effects of Carbonic Acid Gas.—Economic Value of Forests; Effects of Deforesting on American Rivers; Remedial Measures.—Present Condition of American Forests.

THE history of mankind has been at all times much affected by the forest covering of the earth. Modern science teaches that man himself, at least so far as his organic body is concerned, is derived from a long line of creatures who dwelt in trees. His slender, agile body and his delicately constructed, flexible hand owe their essential features to the arboreal habit of his ancestors. It is also possible that the forest habit has left its impress on man's mind as well as his body; for, as appears from a consideration of the existing tree-dwelling species of mammals, they are generally more social, sympathetic, and quicker-witted animals than most of those who dwell upon the surface of the earth. When the brute passed, by some as yet unexplained gradations, into the primitive man, the boughs were abandoned, and the

creature became, in a measure, changed to suit the needs of the firmer earth. For a while, however, the forest remained his fittest dwelling-place. The tropical woods, where man developed, afforded varied food, and the trees a ready shelter from wild beasts of prey.

It is a most interesting fact that the earliest of known mammalia, the most primitive form of those creatures which give suck to their progeny, appears to have been a tree-climbing form, and for a very long period in the earth's history these pouched mammals, related to the kangaroo in all which concerns the nurture of their offspring, carried the thread of our own life through the manifold difficulties and dangers which beset it. Thus the highest group of animals appears to have found in the forests, during the reptilian ages, when the surface of the earth was possessed by a vast array of great predaceous creatures of lower estate, a safe place in which to shelter. The realm of the tree-tops affords even to this day harborage to a very large part of our four-footed kindred. The leafy coverts, the cavities in the gnarled branches, the slender bridges from tree to tree, the spaces which may be cleared at a bound, all give a vantage-ground to creatures which live by their wits, and have to fly from stronger and clumsier enemies. At the same time the array of nuts and fruits or nutritious bark which may be won in the forest, and the range of insects which harbor there, afford plentiful food.

It is only when the "progressive desires," which made him, in essence, man, led him a stage above the lowest level of humanity, that his ancestral woods began to prove a hinderance to him; it is only with the beginning of agriculture that the forests came to be the obstinate foe of his advance,

which was so long to lie across his path. For thousands of years thereafter he was compelled to be a toilful forest-destroyer; from the encumbering woods, with scanty tools—stone axes and fire—he had to win his fields, the material for his dwellings, and the fuel for his hearth.

With the relatively modern development of civilization we are coming to the third state of the relation of man to forests; a stage when he finds that this tree-covering of the lands is necessary for the maintenance of those conditions of climate and timber-supply on which the utility of the earth to him in good part depends. The frontiersman, that essence of the practical man, is still a slayer of woods, and believes that he serves the god of progress by the sacrifice of the forest. But, as knowledge advances, the thoughtful classes become more and more concerned as to the conditions of this earth during the centuries to come, when this swift-advancing ruin of our woods shall have been completed. Most persons will heartily agree that it is our bounden duty to transmit the inheritance which we enjoy in the earth unimpaired to the generations yet to be. It is, unhappily, impossible for us so to manage the store of utilities which the earth affords that there shall be no diminution of the supply for the ages to come. It is probable that the supply of coal will in good part have disappeared by the year 3000; and in the fourth millennial period of our era, a time less remote in the future than the birth of Christ in the past, the metals now in use will have to be won with great difficulty—if obtained at all. Still we may trust the advance of knowledge and skill to compensate for these losses; solar energy may be trusted to afford heat and aluminum to take the place of iron; and the world may be the better for the

change which forced a rustless metal and a dustless fuel into use—at any rate, we see that the supply of mineral resources of the earth necessary for our successors may be prolonged for a time in the future which is long beyond our power to conceive. It is otherwise with the soil-covering of the earth's surface. So far as we can see, that is the least enduring and the least replaceable of any of those features on which the life of the earth depends. It is the harvest of the past; and once lost, it cannot be supplied save by the slow process of the ages.

If we take a handful of any soil which is fit for the use of plants and examine it with the eye and yet more closely with a magnifying glass, we see that it consists of fragments of stony matter in various stages of decay. The nature of soil and its history is treated in some detail in the last chapter of this volume. For our present purpose we have only to note that it is to the progressive decay of these bits of rock that we owe the fitness of the soil for the needs of plants. The fragments of stone riven by various accidents from their original bedding places in the firm-set part of the earth, journey slowly but continuously down the slopes of the land towards the sea. If the inclination of the rocks on which the material rests is steep, the particles move forward with speed towards the rivers. If, as usual, the slope on which the soils lie is gentle, the journey downwards is slow and interrupted. All soil may be regarded as rock matter on its way to the sea. While on the journey the processes of decay, principally brought about by combination of oxygen and other gaseous substances with rocky matter, bring a portion of the soil substantially each year into a state where it may be dissolved in water and so feed the very numerous roots which are everywhere watching for food.

In the natural condition of the earth's surface, when it is covered with a thick mat of vegetation such as we find in the forests or prairies, the soil moves downward so slowly that before its materials come to the banks of the streams and are washed away as silt to the sea, nearly all of the plant food is taken from the waste and fed to vegetation. When, however, the natural coating of vegetation is stripped away and the soil subjected to the strange destructive action of the plough, the rate of transit to the river beds is vastly increased. It is probably made more than one-hundred-fold as rapid as it is in the state of nature. If the slope be steep a single rain of torrential character may carry a given amount of soil further on its way to the sea than it would have journeyed in a thousand years of ordinary conditions.

The most serious misfortune connected with the reckless destruction of our forests arises from the loss of the soil from large areas of land, by which regions naturally fertile have been converted into deserts of irremediable sterility. Already a large part of many fertile regions has been sterilized in this fashion ; and each year a larger portion of this infinitely precious heritage of life slips into the rivers, and finds its way to the sea, because we have deprived it of the protecting coating of vegetation. Therefore it is not alone on account of the surpassing intellectual interest that forests present to us, but also from the gravest reasons of economy, that they deserve to be attentively studied. In the following pages we shall endeavor to set forth, though in mere outlines, the general facts which are known concerning forests—the scientific as well as the economic points together, for they are so united that they cannot well be separately treated.

To find the origin of forests we must go back to the first

stages of vegetable life. The series of plants, as well as that of animals, began in the water, and came thence to the surface of the lands. All very lowly forms of organisms demand a permanent envelope of water, for the reason that they are not provided with any skin which will prevent the drying out of the fluids of which their bodies are in large part composed. It is only after they have attained a certain specialization of development that they can withstand the strenuous conditions to which they are subjected in the atmosphere. The beginnings of plant life in the land were laid in water plants of simple structure; thence they came to fitness for the land conditions on one or more lines of development.

The first land plants of which we have any evidence from fossilized remains are forms allied to our ferns, which appear in the upper Silurian age; but it is improbable that they were the earliest forms which dwelt in the air. It is likely that the lowlier groups of mosses and lichens preceded them in time, and that we have failed to find their remains. For some ages we have very imperfect records of the ancient forests; but we know that during the Devonian period some of the ferns had taken on a tree-like aspect, and probably formed a low, bushy growth in the swamps of that time. As these ferns came to be crowded together there began a great struggle for existence, which has continued to this day, and which has given our forests their most conspicuous aspect. Each individual plant needed to attain a share of sunlight, and so in a way sought to overtop its neighbors. Those which developed taller trunks than their competitors for light prevailed in the struggle for existence, and transmitted their peculiarities to their descendants; those less endowed in this respect generally failed in the race, or had to occupy stations

of inferior advantage. As early as the Carboniferous period the slender trunk, supporting a canopy of foliage at a considerable height above the ground, showed how immediately the needs of the crowded life of the forest had been met by the architecture of these plants.

Cycad in the Botanical Gardens Cape Town South Africa

The trees of the first great forests, those which gave us the beds of peat which, in time, became the coals of the Carboniferous period, were not destined to endure ; they were weakly structures, incapable of withstanding cold, and demanding a larger share of moisture than could be afforded outside of the limits of the swamps of that time. Moreover, their seeds were

generally microscopic in size, containing none of that nutriment which enables the young of our higher plants to start in the race of life with a share of sustenance provided by the parent

It is true that we do not know with any certainty what was the character of the plant life which during the Carboniferous period occupied the uplands of the lands. The coal-beds preserve to us only the swamp deposits of that period. From this fact some students of the coal-measures have concluded that there may have been an assemblage of more highly organized plants on the dryer portions of the earth's surface. It is possible that such may have been the case; but among these coal-measures we have the deltas of numerous streams which should have borne down from the upland some of the drift-wood from the plants which grew there. The fact that none of these deposits have yielded plants of a higher character is fair evidence that the whole of the surface of the dry land was covered by plants of very inferior organization.

Already in the Carboniferous period, and in the Permian, we begin to see the forerunners of a higher form of plants—forms allied to our living conifers and yews; they were relatively rare forms, yet they were the beginnings of a higher order of life. One stage higher on the geological section these early conifers and yews are re-enforced by other large-seeded plants of the same group akin to the cypresses and the cycads. But the greatest advance in the forests consisted in the introduction of the palms. The ferns continue to be an important element in the forests; but slowly they are pushed into a position of inferiority, their places being gradually taken by the higher forms of cone-bearing plants and cycads. Lastly, in the relatively recent ages of the later Cretaceous and Tertiary

there came the higher flowering plants, which give us the prevailing trees of our modern forests—oaks, poplars, elms, and the other familiar broad-leaved plants, which generally send down their leaves during the period of winter rest. Owing to their many advantages of structure and of function, these last comers are steadfastly gaining the room which once belonged to the ancient pines.

The broad-leaved flowering plants, when they take on the tree form, manifest their superiority in many ways; besides their larger seeds, which give some of the parent's strength to aid the nursling at its first struggles for existence, they have a better framework on which to support the great association of buds which constitutes the tree. Unlike the first trees, which generally had hollow or spongy stems, which did not suit the needs of large-branched forms, they have dense wood in the centre, which admirably serves for the support of the colony of buds and permits a great height of the trunk. Thus, while the largest trees of the coal period probably did not lift their branches to the height of one hundred feet, many of the forms of the present day climb for light to the height of two or three hundred feet above the earth. But the greatest advantage of the modern trees is probably found in the fact that they often, by the help of insects and other means, secure a cross-fertilization of their flowers, so that the seeds of one plant are fecundated by the pollen of another. This cross-fertilization appears to give to the progeny of the plant a better chance in the combat for existence than they can secure where the seeds are fertilized by the same flower or those of the same colony or tree.

Another important advance which has been made in the organization of trees is found in the peculiar order in which

the buds, and consequently the branches, are placed in the association of separate growth centres which make up an ordinary plant. In order to secure something like an even share in the advantages of light and air which are so essential to vegetable growth, these buds need to be disposed in definite

A Group of Palms Bay B scoyne Flor da

and orderly relation to each other In the lowest plants this feature of organization is extremely imperfect. The separate growth centres are huddled together without any very definite order. Gradually with the gain of experience which life brings to all the organic series, the centres of growth are brought into definite relation the one to the other. Thus in many of our plants we see that the leaves come off alternately, sometimes

in the form of pairs arising at the same level, followed next above by another pair set at right angles to the preceding, and with a third pair of leaves immediately above the second. In other cases the third pair are not just above the second, but we must proceed yet higher on the stem before we find the circuit completed. In higher plants this order of arrangement of the buds frequently becomes extremely complicated; but in all cases the relative position of the buds seems to be generally ordered so as to secure an even, if rather complicated, relation of the growth centres one to another, to the end that the sunshine may visit all parts alike. This feature in the organization of plants is slowly evolved during the successive geologic periods, and a final success in the arrangement is one of the peculiar advantages which come to highly organized forms.

The result of these improvements is that the struggle is at present mainly between the broad-leaved trees and the conifers. The palms survive only on or near the tropics, and the tree-ferns remain as remnants of a life which, once of supreme importance, is now at an end. Our most successful forests are those of the broad-leaved trees. These predominate in all the great forests of temperate latitudes. Their variety of forms being far greater than those of the conifers, they are ready to seize on any station which the chances of the battle afford them. They have already, to a great extent, driven the conifers to the more northern and intemperate stations, or to the sandier and more arid soils of the northern hemisphere.

With this inadequate, though—we may hope, from the nature of the subject—interesting, glance at the history of our forests, let us go to some tract of primeval woods, to see what are the conditions of the land beneath its mantle of vegetation. Let us take a district where broad-leaved trees predominate,

for there the characteristic conditions of our modern forests are best displayed. There is no place so well suited for this inquiry as the field of the great Appalachian forest, which lies on the uplands of the region within a radius of, say, one hundred miles of the great mountains of North Carolina. In this area are still to be found, perhaps, the finest areas of virgin woods of the deciduous type that remain upon the earth. The trees are of exceeding variety, and man has as yet spared them the destruction which he is soon to inflict.

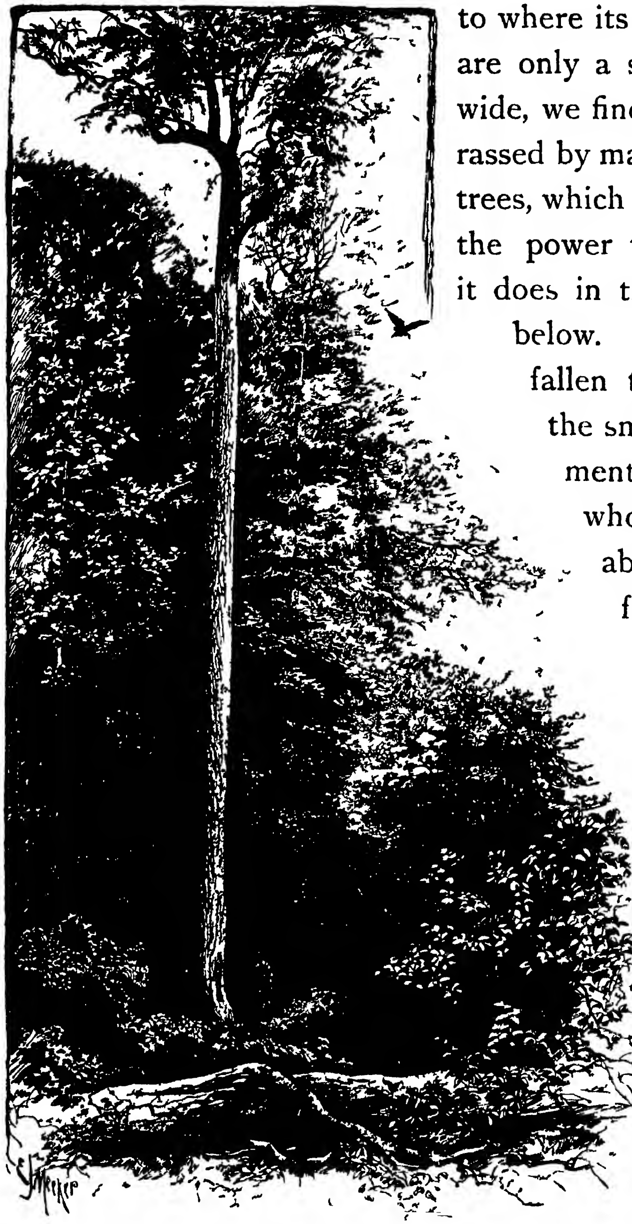
The natural entrance to these forests—often, indeed, the only practicable way into their recesses—is up the channels of the streams. Such were the ways by which the early settlers penetrated the wilderness with their pack-trains or rude wagons, and they still afford the only roads to many of the settlements of this region.* We note that the longer streams of this wilderness, those deserving the name of rivers, are so wide that they cut a channel through the forest; but from the alluvial plain, on either side, white-trunked sycamores and the delicately foliaged willows spring, like the remains of old arches, far out over the water. As the stream narrows, so that its channel is not more than fifty feet wide, these inclined trees, on either side, commingle their branches, forming an arch of interlaced boughs. We note the crystal purity of the water contained in these streams; even in times of flood it contains but little waste from the soil, though it may be discolored by the stain of the decayed forest bed over and through which it has passed. Comparing this stream of pure forest water with

* We can still trace the difficult progress of those modern pilgrims by the names they gave the streams up which they toiled—*Dismal Creek*, *Troublesome Creek*, *Hell-for-certain* and *Pull-and-be-damned Creeks*, and yet more descriptive names mark the stages of their journey.

that which is derived from a valley where there are extensive tilled fields, we see one of the most striking evidences of the evil arising from man's presence. In such a stream from ploughed land we see, after every rain, that the water is exceedingly discolored with sediments, and that, besides the floating mud, a large amount of sand is driven along the

Stream obstructed by Fallen Timber

bottom by the current. The mud is hurried away to the lower rivers, and thence to the sea; but the sand and pebbles gather in *bars* which hinder the course of the stream, compelling it to turn about in a devious way, cutting into its banks, widening its bed, and destroying its former beauty. In times of flood it is a raging torrent; in periods of drought it is often quite dry. Ascending our typical stream still further,



Black walnut Floyd County Ky (Ky Geological Survey)

to where its diminished waters are only a score or so of feet wide, we find its course embarrassed by many fallen trunks of trees, which the stream has not the power to sweep away as it does in the wider channels below. Many of these fallen trees have caught the smaller drifting fragments of wood, the whole forming a tolerably tight dam which, for a time, retains a portion of the flood waters, allowing them gradually to filter through the interstices, thus partly maintaining the volume of the stream in seasons of drought.

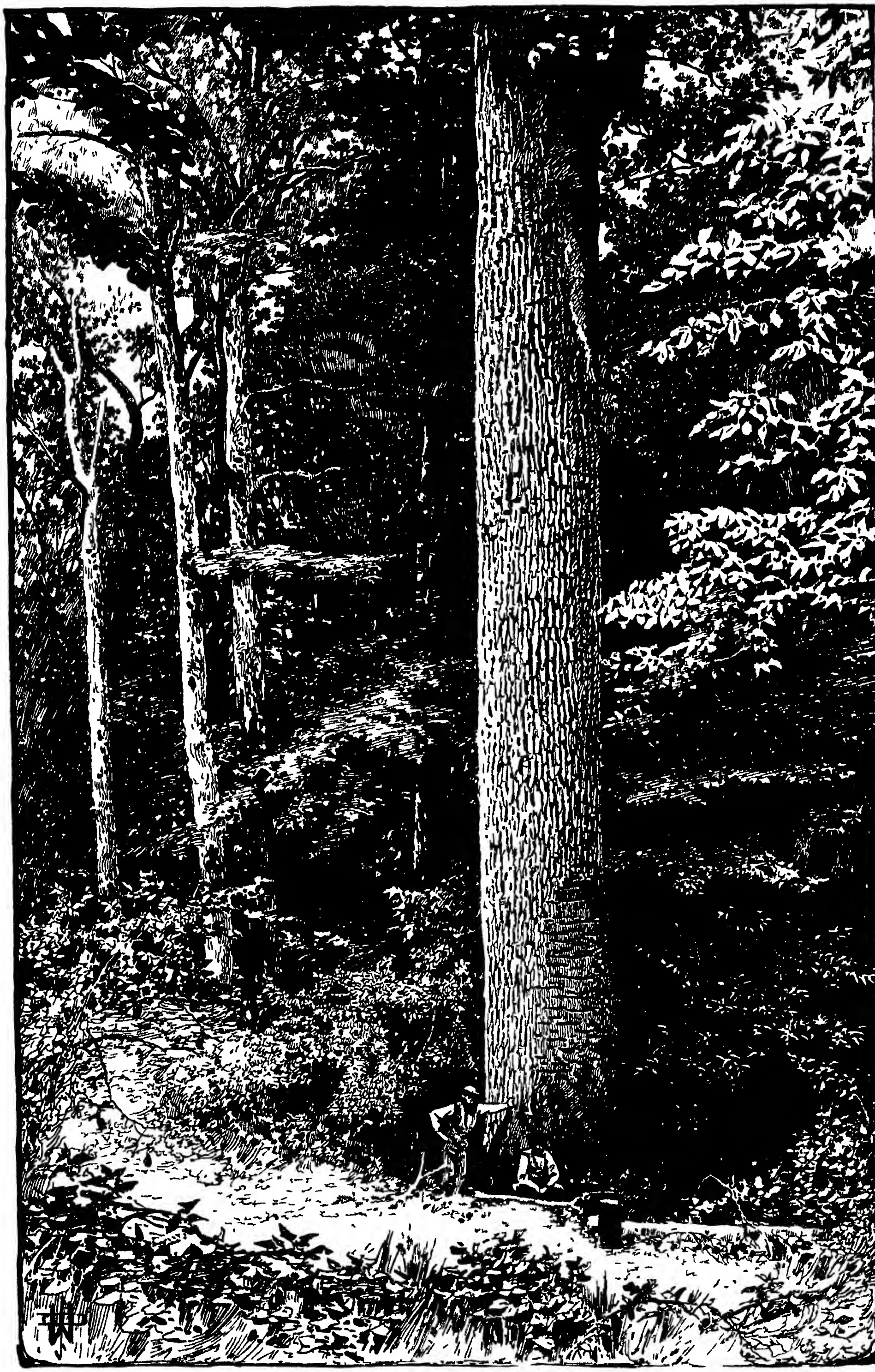
Turning from the way of the stream into the deep shadow of the forest which bounds it on either side, we find ourselves at once in a realm unknown to ordinary experience. Even in winter,

when the leaves are shed, the close-set branches halve the sun's rays, and in summer the brightest sky affords there only a gloaming such as we see in the open ground after sunset. Looking upward, we see the trunks rising, often without a limb, to the height of more than one hundred feet, and to the surface of the great domes of foliage it is often a distance of two hundred feet from the ground. The constant struggle for light causes every space in the great canopy of foliage to be filled by the contending branches. The surface of the

Yellow pine Harlan County, Ky (Ky Geological Survey)

ground is thickly covered by fallen trunks of the trees which have lived their term of life and returned to the earth. Some of them are reduced to the form of. long, low mounds, deeply covered with moss, so decayed and worm-eaten that the foot sinks in them as into snow,—others still keeping the semblance of their giant forms, even in their prostrate position. These trees have rarely been overthrown by the storms; except in the path of a hurricane, the wind is unfelt in these shades; they fall as a strong man by a sudden blow. Those who are accustomed to haunt these primeval woods have often observed how, in the months of May or June, when the air is perfectly quiet, oftenest in the dead of night, while the woods are as still as a cavern, there comes through the silent aisles of the forest a roar as of far-off thunder. The din is caused by some old tree, whose trunk, sapped by decay and overweighted by the burden of its new-made leaves and sap, has fallen into ruin.

The tangle of decayed vegetation which covers the ground beneath the forest is of considerable thickness. On top it consists altogether of the decayed trunks, branches, and leaves, but it shades downward into ordinary dark-colored soil at the depth of a few feet from the surface. This, the decay zone of the forest, lies between the boughs of the air and the branches of the roots. In it go on the most important actions which take place in our forests—actions which affect the history of land and sea. We shall therefore have to consider it in a somewhat pains-taking way. The most evident effect of this sheet of decaying wood, and moss which feeds on the decay, is on the rainfall of the region which it mantles. When, after a season of drought, a copious rain falls upon this spongy mass, the water is for a long time absorbed in the interstices, and



A Tulip Tree, Bell County, Kentucky

does not flow to the rivers. Even in times of very heavy rain the water is slowly yielded to the streams; after a dry period of many weeks this sponge retains a good share of water. A like amount of rain falling on tilled fields or prairies slips quickly away to the rivers, and thence to the sea. The first result is, that when the land is destitute of forests it sheds water like house-roofs, breeding floods after every considerable rain, while in the forests the rain is only slowly yielded to the streams.

A second and less evident result of the spongy character of the forest bed is that, by hindering the escape of the rain-water to the rivers, it increases the actual rainfall of the country. To see the nature and importance of this action, we must turn aside for a moment to consider the origin of the rain which falls upon the land. The original source of this water-supply is the sea, which sends into the lands a tolerably regular annual store of moisture. When this falls as rain or snow, either of two things may happen—the water may go away directly to the sea, or it may return to the atmosphere as vapor to be again precipitated as rain. The chance of its re-evaporation is determined by the speed with which it flows to the streams. From a treeless region it rapidly escapes; in an extensive district of virgin forest it may again and again pass from earth to air, and from air to earth.

The columns of vapor, which in times of summer rain may be seen ascending from every great wood, afford visible evidence of the effect of forests on rainfall. They also may show the observer some of the most beautiful phenomena of atmospheric circulation. In a summer rain-shower the air above the trees becomes much cooler than it is in the recesses below their tents of foliage. This heated air within the wood

seeks to rise, and escapes in great columns wherever there is a wide gap between the branches; as soon as it attains the cooler level above, the moisture is condensed, and the air, before transparent, becomes charged with steam. To replace this ascending air, a broad current drifts toward the emerging streams of vapor, commonly from the higher parts of the forest, where the air, owing to the elevation of the site, is cooler than in the lower levels.

This repeated passage of the moisture from earth to cloud, and from cloud to earth, greatly increases the amount of force which the rain applies, in its falling drops, to the earth's surface; but the rank vegetation protects the surface from the erosion which it would otherwise bring about. Even the forest-clad hill-sides of the Cumberland Mountains, where the soil lies on declivities of great steepness, suffer little wear as long as their natural protection is left to them. But as soon as they are stripped of the garment of wood which has been upon the region ever since, in the far-off ages, they came from the depths of the sea, they wear with great rapidity. The erosion is limited, as long as they are forest-clad, to the stream beds, and there is hindered by the innumerable obstacles of the fallen trees and entangled driftwood. The brooks which are strong enough to clear their beds, and cut into the earth and rock, are few in number; we may often, on the flatter ground, find tracts of a square mile or more in area in which there is not a single stream that ever assails the surface of the earth. As soon, however, as the forest mat is removed, the surface becomes seamed with channels; they often, on the deforested surface, increase one-hundred-fold in their length, and more than that measure in their destructive power. Relieved of all restraint from fallen timber, or the

close-knit roots which enmesh the earth, they sweep the precious soil away toward the sea. In a single day a tilled field may lose from its surface more soil than would be taken from it in a century of its forest state.

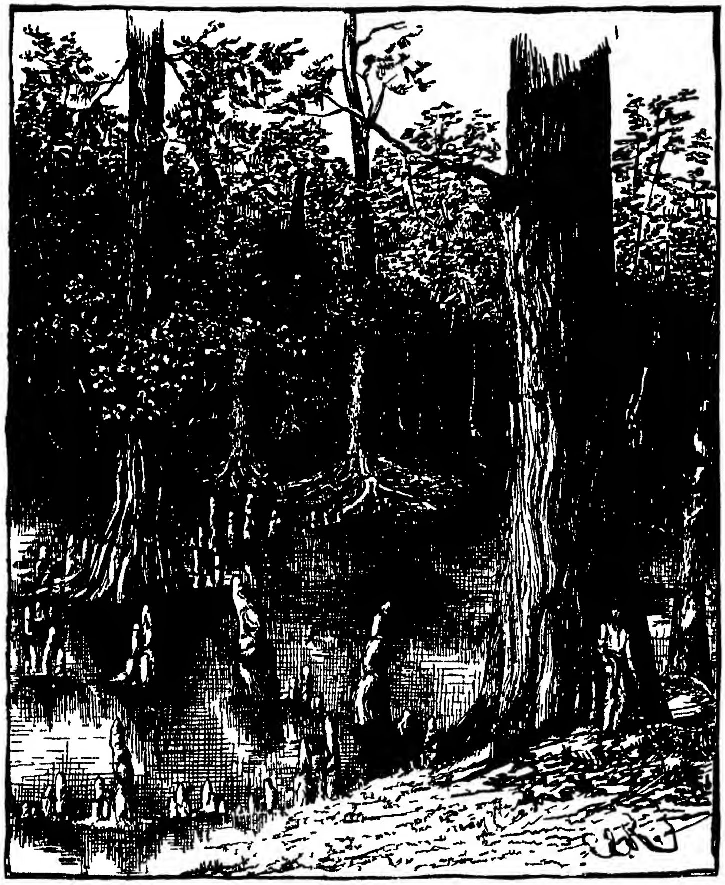
It is in this action of the rain upon the bared surface of the ground that we find the principal danger which menaces man in his use of the earth. The forests probably take each year from the soil as much as our tilled crops; but they not only retain, in the ash of the decayed leaves, branches, and trunks, all which they have removed, but they allow little waste to occur through the action of rain and wind. The use which man makes of the soil, when he tills it, is almost necessarily destructive, not only through the harvests which he removes, but by the incidental waste which occurs in the soil which is washed or blown away to the sea. We behold the results of this perilous wasting in every country which has long been the seat of tillage. In level regions it is least apparent, but in all hill countries it is quickly and often deplorably manifested. The destruction in the United States is most serious in the northern tier of Southern States, but no portion of the tilled districts is quite exempt from it. Brief as has been our use of this American land, a perceptible portion of it, probably as much as one-hundredth part of the tillable area, has been reduced to a state of destitution which it will require ages to repair—which, indeed, is scarcely reparable by the hand of man.

Turning from the general aspects of the forest to the details of its organization, we should first notice the great range in the character of its individual occupants, the various species of trees which form the wood. To the variety of the kinds of trees which are associated together the Appalachian

forest owes, in good part, the wonderful success which it has attained. The coniferous woods of this region rarely have more than five or six species to share the possibilities of a given field; but in the broad-leaved forests we often find no fewer than fifty species, each of which, in a similarly extensive area, finds a place suited to the peculiar capabilities to which it has attained. In this element of variety our American forests far exceed those of Europe which, in a general way, they closely resemble. The deciduous woods of the old world have not more than one-fourth as many species of trees as we find in those of Eastern North America. For instance, in North America we have thirty or more species of oak, to the three or four of Europe, and many genera, including some of the noblest forms—such as the tulip trees, the magnolias, the gums, and the swamp-cypress—which have no representatives in the present European forests.

The advantages arising from this great diversity of species in our American deciduous woods are easily conceived. Each of these kinds has developed a special adaptation to some particular conditions of soil, moisture, or exposure; so that every opportunity which the conditions afford is met by some particular kind of tree, each making haste to avail itself of all the chances which are afforded to it. Thus, in the Southern swamps the Taxodium, or bald cypress, has, by a very singular arrangement of its roots, succeeded in adapting itself to soils which are permanently covered with water—a chance which is denied to other large trees. From each root which extends beneath the swamp about the trunk there arise spurs. These spurs grow upward in the form of stout columns, each capped by a bud-like excrescence, hollow in the centre, and covered externally by a spongy bark, through which the sap

circulates. These bulbous or bud-like knobs are often so large and hollow that they are sometimes cut off and used by the farmers in the swamp districts for bee-hives and well-buckets. The height above the surface of these "knees," as



The Swamp-cypress (Tennessee) showing the Spurs

the projections are called, is so adjusted that in the growing season their upper parts are above the level of the water; if by any chance, as when a mill-dam has raised the level of the pool, the tops of these appendages of the roots are covered during the spring and early summer seasons, the tree inevitably dies. So immediately is this contrivance fitted to the

needs of the situation that a cypress tree on the border of a swamp will have the knees on those roots which extend beneath the water, while those which run under the higher ground will fail to produce them. When the tree is artificially grown on high ground, the knees, so far as observed by the present writer, are never developed; or, at most, remain as trifling spurs on the roots, which do not rise above the soil. Thus the bald cypress, though quite unable to contend with the deciduous trees of the dry forests, has a safe stronghold in the vast swamps of the Southern States, and forms some of the noblest wood of this country.

The sour gum, another of the swamp-dwelling trees, though not so successful in such positions as the cypress, has a contrivance for exposing the roots to the air much like that which we find in the bald cypress in its effects, though the structure is differently devised. In place of sending a spur from the root, the root itself arches upward in a horseshoe form, so that the top of the bend rises above the plane of the water during the growing season. Both this arrangement of the tupelo and that of the cypress probably afford to the tree an opportunity to bring the sap of the roots in contact with the air before it is drawn into the bole of the tree.

The willows, the cottonwoods, and the sycamores, also, find a special field in immediate contact with the water, though they have no such provision as the cypress for dwelling in the permanently inundated ground. They commonly live on the banks of the rivers, and feed on the fertile soil which the inundations bring to the shores. Leaning their trunks toward the streams, and expanding their branches in the open space above them, they, like the cypresses, win a

realm where they do not have to contend with their stouter competitors for light and air.

The alluvial lands on either side of the streams, regions liable to frequent floods, are possessed by species which have a less endurance of humidity than the forms just mentioned, but are still more tolerant of long-continued floods than the most of our deciduous trees. Here we find, especially in the southern part of the Appalachian forest, pin-oaks, certain kinds of elms, the swamp chestnut-oaks, gums, tulip trees, etc. So completely is the forest adjusted to the conditions, that the alluvial lands of the rivers generally bear a different assemblage of trees from those of the smaller streams.

In the upland districts the trees are distributed in a more varied manner than in the parts of the surface which are affected by inundations; still, even there the arrangement is rather according to evident law than according to the indiscernible complexity of law we term chance. Though the species are somewhat affected by the accidents which plant the seeds, the predominance of any species is always indicative of some peculiarities of soil or exposure. So accurate is this delimitation that the early settlers in the forested Western States always and unerringly chose their places of settlement by the nature of the timber. Where blue-ash, black-walnut, or coffee trees abounded, they knew that they had the most fertile soils; beech woods indicated a soil of less fertility, but still of endurance to tillage; white-oaks a soil of lower grade, but suited to certain crops—as, for instance, to tobacco; a predominance of red-oak trees, a yet less suitable ground; and a wood of black-oaks, or "black-jacks," the most unpromising field of all.

In a hilly country each of the varying aspects of the sur

face brings its peculiar influences to bear on the distribution of the timber. So sharply is the distribution determined by the compass direction of the slope, and the consequent share of sunshine which it affords, that a skilled observer may, in cloudy weather, tell the direction of his way by a careful study of the forest

We should also observe that the same immediate and

Black jack Oaks Todd County Ky (Ky Geological Survey)

complete adaptation of the trees to their conditions is shown in the way in which they recover their possession of abandoned fields, and of the tracts which have been deforested by hurricanes or fire. A certain limited number of species lead the way to the re-possession of these districts from which the forest has been expelled. If the ground has been long under tillage, as many of the worn-out fields of Virginia have been, the sassafras, persimmon, black- and red-oak are apt to

be the first of the forest trees to establish themselves. If fire has done the work, then the poplars and birches have, in most districts, the best chance; if it be a hurricane's path, the ground is sure to be full of seeds and young trees, and it is any one's race, with the predominant oaks generally in the lead. South of Virginia, where the soil is sandy, the "old-field pine" is generally the pioneer of the forest's re-advance.

Nowhere is the process by which the forests recover the possession of fields from which they have been driven by the plough more victoriously shown than in New England. In that region the skirts of every wood are bordered by a thick-set undergrowth largely composed of our bayberry and huckleberry bushes, which rapidly restore to the soil the surface coating of mould necessary to the best growth of larger plants. The nutritious berries are eaten by the birds, and the seed scattered over the fields, so that in a few years after tillage has ceased little mounds of foliage are scattered here and there over the open ground. Each of these colonies of fruit-bearing plants becomes a natural cradle for the nurture of any chance seed of larger trees which may be wafted to the sheltered station they afford.

The controlling conditions in the distribution of the forest trees are: first, the characteristics of the species; second, the nature of the soil; third, the chance of distribution of the seed; and, lastly, the assaults of the animal enemies which each kind encounters. Some species—as, for instance, the black-locust—are extensively subjected to insect enemies. The oaks, on the other hand, are, on account of their acrid sap, tolerably well protected from such dangers. As a whole, our deciduous trees have established, by one device and another, a tolerably strong defence against animal pests. In

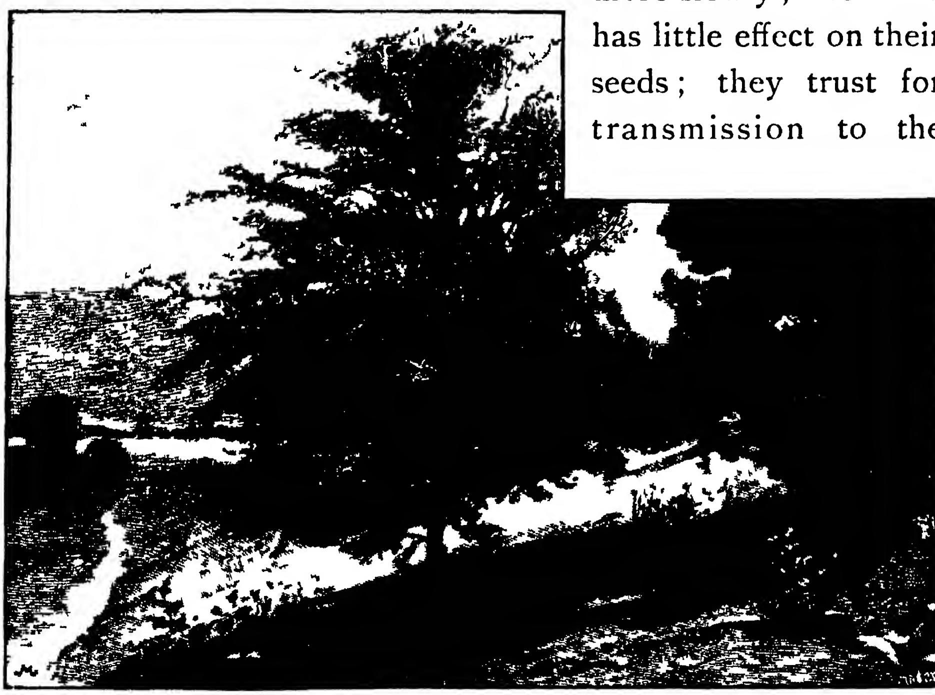
fact, they owe their continued existence to their success in preventing this class of dangers. Now and then some new enemy arises, which imperils and may destroy a species. An instance of this sort has recently come to the attention of the present writer from some study of the forests of Kentucky, which was undertaken with the co-operation of his assistants It appears from these observations that the white-oaks of that district, which, despite the ravages of the axe, still constitute some of its finest forests, are in the way to disappear, owing to their failure to reproduce their kind. There are singularly few young white-oaks in these woods, but an abundance of the less desirable varieties of red- and Spanish-oaks. The reason for this seems to be that the nuts of the white-oak are more palatable to the squirrels than those of the other species; so these creatures industriously seek them out, and only resort to the more bitter and probably less nutritious nuts of the other species when those of the white-oak fail them. In similar ways other animals react destructively upon other forest trees. The introduction of swine in the settled portions of the forests brings a greedy and judicious palate to consume the more edible nuts, and so destroy the progeny of many trees. But what is one kind's loss is another kind's gain; with the destruction of one species, its competitors find a fair field and hasten to occupy it.

There are evidently two principal limiting causes which determine the growth of forests—these are drought and cold. When the rainfall is less than serves to keep the roots moist during the period of growth, or when the growing season is too brief to permit the ripening of the new wood of a tree, the forests find their limit. In the struggle with the cold the coniferous trees have, in general, the advantage of the broad-

leaved group, possibly for the reason that in the former class a portion of the foliage holds over the winter; thus there is less to do to bring the machinery of growth into operation, and the process of annual increase can be more quickly accomplished. So, too, in the struggle with arid conditions the conifers, or narrow-leaved trees, appear to be, on the whole, more successful than the broad-leaved trees, probably for the reason that their rigid and scanty foliage expends less water than the soft and expanded leaves of the other group. Thus the conifers have come to occupy the greater part of the scantily watered districts of the Rocky Mountains, as well as the regions of the far north up to the limits of the forests which stretch toward the North Pole.

We have already noticed the process by which forests recover their possession of ground from which they had been driven by the destructive work of tillage. From time to time the return of these native woods to the fields from which they have been dispossessed by natural processes occurs in a majestic way. The successive glacial periods, which from time to time in geological history have swept the high latitudes of the several continents, destroy not only the forests but the soils on which they are fed in a wide-spread way. Thus after the last ice time, when with the climatal change the glacier disappeared, the northern part of North America —in general the country north of the parallel of 40—was a waste of sand, gravel, and other detrital materials, containing no trace of the old soil. As the glaciers disappeared this vast area was a free field open to the forest species which had been driven southward before the advance of the ice-sheet. Into this area the plants made haste to enter. The small-seeded trees, such as the willows, which have germs that can be

readily carried by the wind, were fleetest-footed and had the choice of their appropriate stations. Other trees, such as the maple, the seeds of which, though heavy, have parachute-like wings which may carry them far, move also with a certain speed towards their goal. The heavy-seeded trees, such as the walnuts, the hickories, beeches and oaks, are compelled to travel more slowly; the wind has little effect on their seeds; they trust for transmission to the



Winged Elm (showing foliage on the edge of a forest), Cumberland Valley, Ky

short advance made each generation by the length to which the boughs spread from the parent trunk, or they secure a wider scattering by squirrels or other small animals which eat the nuts and are thus led to carry them about either in their jaws or stomachs. The result is that the heavy-seeded trees have lagged behind in the race for high latitudes, while the light-seeded firs, willows, and other plants which are easily dispersed have won the greater part of the fields left vacant

by the retreat of the glaciers. We perceive by the fact that they will grow much further to the north than the stations which they now occupy, that the large-seeded plants are hobbled in the race for high latitudes, while the light-seeded plants have generally attained as high latitude as they can possibly withstand.

In their race for the high north the forest trees are clearly subject to the influence of selection in such a way as to determine the death or life of many forms; so, too, when driven southward by the ice-sheet the process of automatic choice, which we term the survival of the fittest, occurred. When the ice-sheets appear in high latitudes and thence move southward, each species must migrate or perish; the individual forms of course are not free to move, but the succession of generations must win their way southward with sufficient speed to keep ahead of the on-coming ice. If any species failed in this work it would inevitably be overwhelmed by the glacier, and thus disappear from the face of the earth. In the return to the regions made vacant by the disappearance of the ice, the process of selection would be accomplished in a different way, but to the same effect. The species which did not move northward fast enough would find the climate change more rapidly than their dwelling-place, and so, if they did not reconcile themselves to the new kind of weather they would perish, or they might be overwhelmed by other and stronger species which marched far into their territory. Thus the fleet-footed forms would always have, other things being equal, an advantage in the race for life. But "other things" are not commonly equal in the work of nature; while the large-seeded forms are slower to make their great migrational journeys, the very largeness of their seeds provides them with more

sustenance, fits them better for the struggle for life which comes in infancy. Thus, though the heavy-seeded trees are plodding back into the old glaciated fields slowly, they are, nevertheless, moving with a stubborn determination which bids fair to give them possession of all those wide realms.

It is an interesting fact, which we had occasion to notice a few pages back, that the forest trees of Europe are of much less variety in their kinds than those of North America. The reason seems to be that the glacial periods in Europe serve to overwhelm the vegetable life, and this because when the glacial envelope comes upon the continent and forces the army of plants down to the southward, they have no secure field for retreat, as in North America, but find their migrations stopped by the great gulf of the Mediterranean. It is likely that the wide difference between the richness of the forest life in the Old World and the New is, in part at least, determined by this cause.

There remains still the need of explaining the absence of forests from that part of the so-called prairie districts of the West where the water-supply is abundant for the nurture of forests, and where, indeed, a great variety of native forest trees grow, when planted, with singular luxuriance. Several recondite explanations have been devised to account for this peculiarity. It has been asserted that these prairies are unfavorable to the growth of trees because of the fineness of the soil ; but without considering how this *fineness* can act, it is easy to see that the soil of the Mississippi delta region, which intersects the prairie districts, is even finer-grained than that of the treeless plains. Others have held that these regions were the floors of great lakes, which, after the glacial period, were quickly possessed by grasses to the exclusion of the

trees. But it is easy to see that, even in the best of our existing grass lands, the forests generally manage swiftly to

A Sycamore Tree in White River Bottoms near Wheatland, Ind.

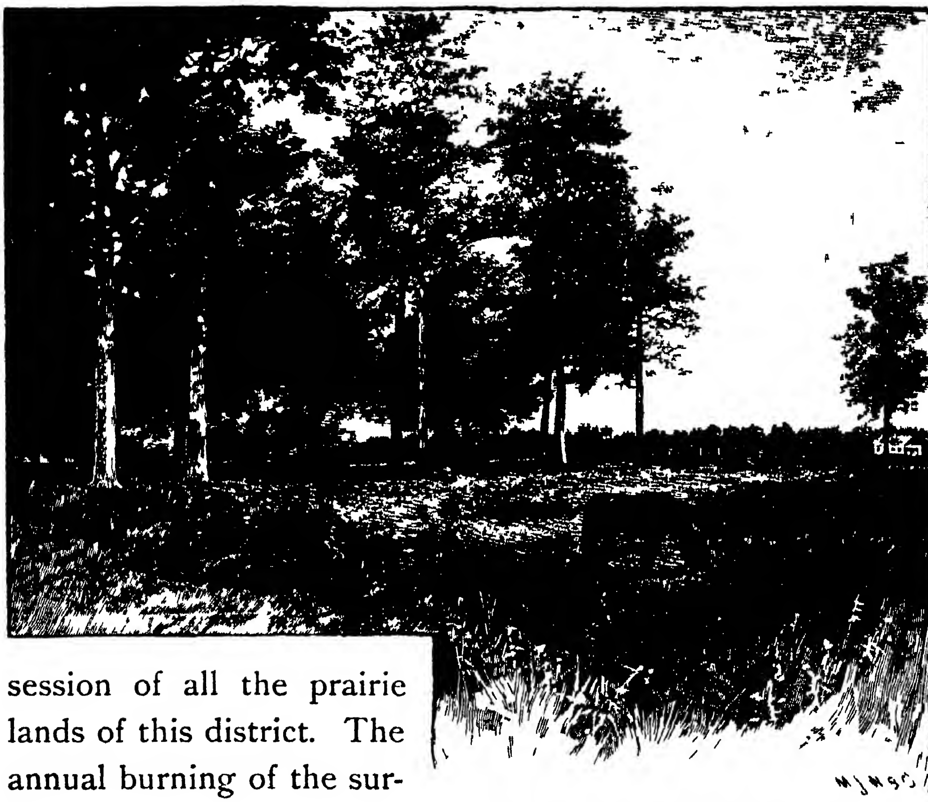
regain possession when they are allowed to pursue their way without interference from man.

In accounting for the prairies, it will not do to seek their origin in a single cause. There are certainly two elements at least in the causation which have operated with different

degrees of effect in different parts of the Western tracts. In the region beyond the Mississippi, where the annual rainfall is less in amount than twenty inches, drought alone will perhaps serve to explain the treeless conditions; farther to the east an artificial cause—viz., the fires which the Indians were in the habit of setting to the grass of the open ground and the leaves of the woods—will account for the destruction of the original forests. These annual forest fires were kindled either to drive the game toward the hunters or to aid the growth of the fresh grass which springs up after the conflagration. In this way the prairies were extended eastward to Indiana and south to the Ohio River. At a point west of Louisville, Ky., the prairie country crossed that stream, and extended south to the Cumberland River, near where Nashville now lies. In this latter region we have a clear example of the process by which the country was deforested. When the whites first came to the Ohio valley, this prairie region between the Ohio and the Cumberland Rivers occupied the whole belt of limestone land of Western Kentucky. Skirting the southern border of the western coal field, it extended westward across the Cumberland and Tennessee Rivers into the low table-land which lies between the last-named stream and the Mississippi River. About five thousand square miles of this area were actually deforested, except where, beside the scanty streams, the ground was too moist to permit the ravages of the annual conflagrations. On the border of this area the old trees were not destroyed, but remained in the form of a very open forest. The younger growth was, however, wanting. The reason for this is plain: The older trees have a very thick outer bark, which served to protect them from the damage which would be inflicted by the momentary heat of the burning leaves, while the

tender stems of the saplings were easily destroyed. Thus it came about that when the old trees died they left no successors, and so the prairie steadily widened its area.

As soon as the Indians ceased to use Kentucky as an annual hunting-ground, the forests rapidly regained their pos-



Ash Grove Ashland Fayette County Ky

session of all the prairie lands of this district. The annual burning of the surface ceased in the latter part of the last century; in the second decade of this, the whole of this great area was covered by a thin wood of young trees, which quickly closed into a dense forest. At the present time all the parts of this field which have not been deforested by man are thickly wooded. Some indications of a similar process of forest restoration may be found in Indiana and Illinois; but in those regions the annual rainfall is less, and

summer droughts, which are calculated to prevent the establishment of the young trees, are more frequent and more prolonged than in Kentucky.

Turning now to consider the underground work of the forests, we find there a realm of activities of interest equal to that of their more visible portion. The leaf-bearing branches of the trunk are hardly more extensive than those which penetrate the soil. The main function of these underground branches is to supply the ashy element of the plant, which they take, dissolved in water, from the soil, and, in the form of sap, send upward to the leaves for further elaboration. In this work they penetrate, not only horizontally through the existing soil bed, but often enter into the crevices of the rocks which have not yet been converted into earthy matter. As soon as the roots find a profitable way into these fissures of the rocks beneath the soil, they increase in size and exert a powerful rending action, riving the stones asunder. Each weak place of the fragments is in turn sought out, and the hard mass is in time reduced to small bits as effectively as by the blows of a hammer. This work often goes on at a depth of ten feet or more below the surface; and so forest trees operate to produce soils of great depth, while the grasses and tilled crops have much less effect.

The greatest work of the forest on the subjacent earth is accomplished by the action of the deep layer of decaying vegetation which it forms upon the surface. This layer consists mainly of carbon, which, by the process of decay, is combined with the oxygen of the air in the proportion of two atoms of the latter to one of the former substance. This combination is known to chemists as CO^2, or carbonic dioxide; or, in the old nomenclature, as carbonic-acid gas. It is,

as the old name indicates, a gas; and though heavier than air, in good part escapes into the atmosphere in time to be reclaimed by the leaves and to return to some forest bed. This gas is extremely soluble in rain-water, each part of water taking in many times its bulk of the gas. At first sight this seems a very commonplace fact; but, as we shall see, on it depends, in an intimate way, a most important part of the mechanism of the earth.

When the water falls on the surface of the earth it has little power to take into solution the substances which compose the rocks. The charge of carbonic-dioxide gas increases this dissolving capacity in a wonderful manner; for instance, when pure rain-water will dissolve one portion of lime, the same water when charged with the gas will take fifty times as much into solution. So with nearly all the substances which the water encounters; its solvent influence is vastly increased by the carbonic dioxide contributed by the forest bed. Along with this gas the forest bed adds to the water a number of other acids derived from the decaying vegetation, all of which serve in different degrees to promote its solvent action.

The most immediate effect of this action is to enable the roots to appropriate the mineral matters of the soil, which they cannot seize on until they are brought into solution. Thus the dead plants serve the functions of the living in a most important way. But it is in the remoter effects of these carbonated waters that we discover their most important rôle. Soaking deep into the earth, they find their way slowly into the interstices of the rocks, and take from them something of their contents. When, after a long journey in the underground, they emerge in the springs, they bear away to the sea a share of about all the substances which are found in the

crust of the earth. The ability of water to carry away these materials is mainly due to the influences exerted by the thick coat of decaying vegetation through which it passed on entering the earth.

The contribution which these spring-waters make to the sea provides it with that wide range of dissolved materials which is necessary for the sustenance of marine life, and for the formation of the deposits composed of organic remains. The mud and sand which is carried by the rivers to the ocean has relatively little value as an agent in such formation, for the reason that it is all deposited near the mouths of the streams. If this work of underground water were not done, or even were it done with half its present efficiency, the oceans would, when their present store of dissolved mineral matters was exhausted, cease to maintain their vigorous creative work.

We thus see that the soil coating of the earth's surface, which is, in the main, the product of forest action, is a necessary part of the machinery that fits both sea and land for the uses of organic life. In the vast enginery of the earth, where there are so many parts absolutely necessary for the work of supporting the functions of the whole, it is hardly possible to speak of any one contrivance as of pre-eminent importance; still this complicated work of the forests may fairly be considered as of critical value to the interests of life.

The foregoing considerations, though all too brief for our need, will enable us to consider the economic aspects of our American forests in a summary way. It is clear, from what has been said, that the most important aspect of the problem concerns the soils. The great question is, What will be their fate in the deforested condition into which they must be

brought for the chief uses of man? It is clear that in all countries the waste arising from the erosive action of the rain is far greater in tilled ground than in forest-clad districts. Indeed, in forests we may say that the soil is ever deepening, while in tilled lands it is almost always diminishing in depth. There are certain conditions in this country which make the rate of wear more rapid than on the European continent. The rainfall of the district east of the Mississippi is greater and more torrential in its character, and therefore more erosive, than in the old world. Therefore we may expect danger from this cause in much less time than it has been encountered in other countries.

It is evident that, as far as this evil is a necessary accompaniment of tillage, it must be borne as best it may; but in large part it is capable of correction by the exercise of a little intelligence. As the amount of this erosion is, in general, directly proportional to the steepness of slope of the ground, abrupt declivities should not be subjected to the plough, but retained in timber or in grass. If tilled at all they should be terraced, as is now much of the steeper ground of Europe.

The next danger is that which arises from the sudden precipitation of the rainfall into the streams when the forests are cleared away. This process brings about serious inundations in the season of rain, followed in the times of drought by a drying up of the streams which were once, by the action of the forest, maintained throughout the year with a more equal flow. This evil is already manifested in the condition of the Western rivers. With the removal of the forests, the winter floods increase in magnitude, and the summer droughts leave so little water in the streams that they are constantly becoming less serviceable for navigation. Moreover, the amount of

soil which is swept into the rivers is so great that they are embarrassed by it; their channels are shallowed, and the currents, driven to and fro, widen the water-way, and thereby shallow the diminished streams in the season of low water.

In part this evil is, like the first mentioned, inevitable, for it is due to man's necessary interference with the forest covering of the earth; still it may be minimized. The law has interfered to prevent the owners of the Californian placers from pouring the waste of their hydraulic washings into the streams, because they harm those who live and labor on the banks below; on the same principle, we may fairly require the tiller of the soil to keep the soil of his fields where it belongs, by adapting his treatment of the ground to the limitations which its nature imposes upon him. When the present crude notions of the rights of the owners of land have become qualified by reason, when it is accepted that the possessor of land has only a reasonable usufruct in the piece of the earth of which he holds, and that he has no right to use it wastefully or to his neighbor's injury, we may meet this problem with fair success.

It seems to the present writer that the government has a right to require that all the existing forests, the preservation of which may be deemed necessary to the good of the valley in which they lie, should be maintained in their present condition; or, if removed, that they should be replaced by equivalent plantations of timber. This can be so managed that the owners shall retain all that these woods have of present value—viz., the timber, as it ripens, for exportation. The owners may lose an "unearned increment" of prospective value of these lands for tilled fields and town sites, but concerning this justice need not be seriously troubled.

So rapid, indeed, is the appreciation on the value of forest products, that the restriction would bring little that can be called hardship to the owners of these forests. The damage already done to our rivers by the removal of forests is not so great that it cannot be borne; moreover, it can be in good part compensated by a proper system of reservoirs, in which a portion of the winter flood-water may be retained until the times of summer drought.*

The next disadvantage arising from the removal of the forests is due to the loss of the secondary rainfall, or that arising from the evaporation of the moisture retained by the spongy bed and embarrassed streams of the primeval woods. Fortunately, this country has in the most of its originally forested regions a greater surplusage of annual rainfall than have most of the other civilized districts of the world, and, therefore, can better afford to lose the valuable aid of occasional showers such as this evaporation induces. Moreover, the rapid extension of irrigation, which is sure to take place in the more arid sections of the country, will afford a similar and, perhaps, in time an equal supply of moisture for these secondary rains.

We come now to the uses of forests as sources of timber-supply. From this point of view we find their most immediate and unquestionable value to man. The ages of stone, bronze and iron have succeeded each other in the arts, but through them all man has always been a wood-using animal. Only the beaver approaches him as a consumer of timber. While the general substitution on the hearth of coal—the product of ancient forests—for the timber from the living

* See, for further consideration of this point, The Floods of the Mississippi Valley, Atlantic Monthly, vol. li., p. 697.

woods—has diminished one element of man's ravage, the development of modern society steadfastly increases the tax which each individual levies on the forest. Although some dreamers conceive that in the future man may make use of aluminum as a substitute for wood, there is no reason to believe that this change will ever be accomplished. So far each addition of cheaper metal has served to increase rather than to diminish the demand on our timber-resources, and this is likely to be the case in all the foreseeable future.

The general abandonment of wood as a fuel has, however, changed, in an important way, the nature of the drain upon our forests. For firewood, the forest is cleared away; for construction-timber, the natural growth is not usually destroyed—only the ripe trees need be removed, leaving the physical character and influence of the forest essentially unchanged. Where, as in Germany, the forests are generally plantations owned by private citizens or by the government, the whole field is, it is true, cleared away at once, but the laws require that before each clearing is effected a similar area shall be freshly planted; thus the forest is kept intact.

The present condition of our American forests, except those of the cordilleran region, is by a fortunate combination of accidents in a much more satisfactory shape than might have been expected from the rapid growth of our population. In the first place, the head-waters of the streams of the eastern part of the continent lie generally in the rugged hills of the Appalachian Mountains, where the soil is not the most fertile and, therefore, the inducement to tillage slight. On this account the most important forests for their effect on rainfall and on the water-supply of our streams often remain

in a comparatively little-changed state. Next, the agricultural districts of the Southern States, where a great deal of the old forest has been cleared away, are regions of large rainfall, and generally of tolerably level surface, so that neither the evils of desiccation nor those arising from the washing of the soil to the sea have as yet proved very serious. Still further, the wide prairie lands of the Mississippi valley have taken into their forestless areas nearly one-third of the soil-tillers of our population, and so have given us a field of expansion without much immediate effect on the area of forests. The timber-supply for these prairie States has largely come from the region about the great lakes, and its removal has therefore had little effect on navigable streams or on the summer rains.

Lastly, the abundant and cheap transportation of food-products from these prairies to the Appalachian district and the Atlantic shore lands rescued their forests from the axe by making the tillage of all but the most fertile lands unprofitable. The effect of this Western food-supply has been so great that, since the middle of the century, it has not only in good part stopped the process of clearing away the Appalachian woods, but in certain districts, especially in New England, extensive areas of land which had been long under tillage have been allowed to return to the forest state. In Massachusetts, for instance, it is probable that the area now possessed by timber is considerably greater than it was at the beginning of the present century. The present writer, in his many journeys through this State, has observed many thousand acres of woods where the marks of former tillage—corn-hills, and walls composed of bowlders gathered from the once cleared land—attest the sometime clearing away of the

forest; but he has not, in all, seen as much as one thousand acres which had recently been won to the plough.

Thus the matter of forest preservation is, in the main, a problem for the immediate future: save in the valley of the Ohio and, perhaps, on the Adirondacks, the process of destruction has not as yet begun to give extremely serious results.* It seems, however, certain that the conditions which have postponed the question of forest management have about exhausted their influence, and that in the next half-century we shall imperatively need a systematic control of our remaining timbered districts.

The Western prairie lands, or at least those parts of that vast region of treeless plains which are suitable for tillage without a costly system of irrigation, are generally possessed by settlers. Already the population begins to press back upon the older districts, which were passed by as long as the best lands of the West were to be had for the asking. A large part of the Appalachian forest district, though affording poorer soils than the prairies, is second-class land which can be profitably tilled if we count as profit the interest of the farmer alone, without considering the effect of this tillage on

* The destruction of forests in the cordilleran region has been much more serious than that in the eastern portion of the continent, though it has, in the main, been accomplished by fire, not by the axe. The loss of these Rocky Mountain forests is especially to be regretted, for the reason that the deforested areas, owing to the prevailing dryness of the climate, do not spontaneously return to the timbered condition as they do in the regions east of the Mississippi. It is a rude compensation for the loss, that this destruction only deepens the already hopeless sterility which marks the greater part of the mountain region of the West. On the Pacific coast there are, as is well known, superb forests of coniferous woods which are in much danger of ruin. For many reasons, however, these forests are of less critical importance than those of the eastern district. They do not greatly affect the regimen of important streams, and are almost without influence on the rainfall.

the rest of the country. Considered from a wider point of view, we cannot afford to have it tilled; for the reason that we need the existing forests for the supply of timber they may afford, as well as for their effect on the rainfall and the water-supply of the rivers in whose valleys they lie.

The forests are a precious heritage of man. They provided him a cradle; they furnished him the soil, and they still offer him their help in some of his greatest needs. No man has the right to destroy them when their destruction means calamity to his fellows or his successors. To give the individual the right to appropriate and overthrow them at his will is to constitute him a cruel despot; if such privileges exist in the laws framed by a short-sighted past, it is time they were annulled.

THE ORIGIN AND NATURE OF SOILS.

Relation of Soils to Organic Life.—Origin of Soils; Effects of Solar Heat; Influence of Atmosphere.—How to Begin the Study of Soils.—Stages of Soil Formation; Action of Rain; of Frost.—Effect of Lichens; of Higher Plants.—Study of Mountain District.—Effect of Joints; of Roots of Trees.—Processes of Torrent Valleys; Floods; Rock Avalanches.—Diablerets; Goldan; Yvorgne; White Mountains.—Alluvial Plains; Processes of Formation of; Soils of.—Upland Soils; Immediate Derivation of; Structure of; Processes of Formation of.—Process of Ablation—Glacial Soils; Conditions of Continental Glaciers; Nature of Glacial Soils; Origin of Fertility of Soils; Phosphate Matter: its Origin.—Effects of Penetrating Air; Means whereby Air enters the Soil—Effects of Tillage; Action of the Plough.—Proportion of Plant Food in Soil.—Effect of Ferments.—Comparison of Natural and Artificial Conditions of Soil.—Working of Soils under Tillage.—Man's Duty by the Soil.—Effects of Irrigation.

THE relation of organic life to the earth is so familiar that it does not seem curious. We are accustomed to see the plants and animals on the earth's surface; they appear to belong there, and we rarely note the very peculiar way in which they manage to draw their sustenance from the under world. When, however, we narrowly examine the circumstances which make it possible for organisms to be nourished by the earth, we find that this work is accomplished by a very elaborate mechanism which depends for its successful operation on extremely complicated conditions. In the following pages I propose to set forth in a general way the history of that superficial part of the land surface which we term soils, to show how it has come into existence, and by what means it is made to afford a medium of communication between the so-called dead matter of the earth and living beings.

To understand the origin of soils we must begin by studying the earth's surface in a large way. It is necessary to note at the outset that the soils are produced not by forces resident in the earth itself, but in those which come to it from the celestial spaces. Left to itself, the earth would have presented no trace of soil. If it had remained in the condition in which it was when it cooled down from its original molten state, its superficial parts would have had the character of lava streams when they have just become solid. It is to the heat which comes to our earth's surface mainly from the sun, but in a certain measure from all the fixed stars as well, that we owe the existence of this medium between the inorganic and the organic world which we find in our soils. This heat furnishes the motive power by which the rocks are pulverized. Water and the atmosphere, the two great instable envelopes of the earth's surface, afford the machinery of the mill. This mill produces a layer of comminuted rocky matter more or less commingled with organic waste, in which plants may find a place for their roots; whence they may draw the material for their bodies. This material is contributed by plants to animals, and affords the opportunities of life for those higher organic forms.

The best way to begin the study of the soil is to observe what takes place when a bare surface of rock is laid upon the land as by a stream of lava, or in some newly-made island of the sea; or, to take a more familiar case, we may examine the exposed rock of some old quarry where a considerable area has been deprived of its soil covering and left slowly to recover this coating of detrital material. Nearly every part of the civilized world will afford the student such opportunities for observing the nature of the process by which soils are made. Even where quarries do not exist, an old pave-

ment will in many cases show some part of this interesting process.

The stages of this process of soil-making are as follows: The sun's heat warming the waters of the earth's surface evaporates them and lifts them high into the atmosphere, then they fall back in the form of rain or snow. Falling in the form of snow the water has the least influence in making soils; in the form of rain its effects are more immediate and important. The snowflakes come down with no perceptible force, but the drops of water, as we may observe by holding the bare hand exposed in a heavy shower, strike a certain blow on the surface. Their stroke tends to loosen any grains of sand or mud which may be by decay partly severed from the rock. The result is that in a short time a considerable amount of finely-divided *débris* is accumulated on the surface, gathered in the little hollows which are always found there. The water soaks into the interstices of the stone; it dissolves the material which binds the grains together, and so prepares them to give way before the blows which subsequent showers bring upon them. Where the frost operates on the surface by expanding, the water which has been absorbed by the stone still further serves to break up its structure. In the quarries of granitic rock which abound in eastern New England, a few years of exposure so far soften the stone that certain lowly forms of plants may become attached to it.

The first forms to seize upon a surface are lichens, plants which have no distinct roots, but which absorb a certain portion of mineral matter by the broad adhesions which bind them to the place upon which they fasten. These plants are so organized that they may remain entirely dry for a good part of the year, becoming active only at those times when

the moisture of the air and that of the surface on which they rest afford them sufficient water for their vital functions. As soon as the surface has become, in a measure, covered with lichens, the decay of their forms supplies the water with a certain amount of carbonic-acid gas, which vastly enhances its power of disintegrating the stone. Ordinary water, as it falls in the form of rain, can dissolve not more than one fifty-thousandth part of its bulk of limey carbonate, or ordinary marble, while if charged with carbonic acid it will dissolve one-thousandth part of its mass of that substance. Thus, as soon as vegetation finds a foothold on a bare surface, it vastly enhances the rate at which the air can proceed in forming soils, for in proportion as the solvent power of the water is increased its effect in disintegrating the rock is increased.

As soon as the surface has secured a coating of lichens the process of soil-making goes on with increased rapidity; the moving grains of sand released from the bed-rock become entangled between the broad fronds of the lichen, and are no longer washed away by the heavier rains. In a short time enough rocky matter is accumulated to afford a place in which the higher plants, those bearing roots, may find a foothold. They grow swiftly in the short period when the thin soil remains moist, and when dying contribute their remains to the developing soil. In the course of a century, if the slope of rock be not too steep, a thin coating of *débris* is spread over its entire surface, and may afford sustenance not only to mosses and lichens but also to plants which maintain their life during the whole summer. In another hundred years herbaceous plants may find the soil thick enough for their needs, and even the smaller trees, those which do not require to strike their roots into a deep layer of earth, may fasten

themselves upon it. In this way, in a period which is but an instant of time measured on the term of geological ages, an area of rock which has been by accident, as by an earthquake shock, deprived of its soil-coating, or on which that coating has never previously existed, may be formed ; and so the region is brought again into the realm of living beings.

Although this small illustration serves to show the more general facts concerning the formation of soil, there is very much concerning their history which remains to be told. Like all other illustrations drawn from limited area it only aids the mind to conceive the larger operations of nature

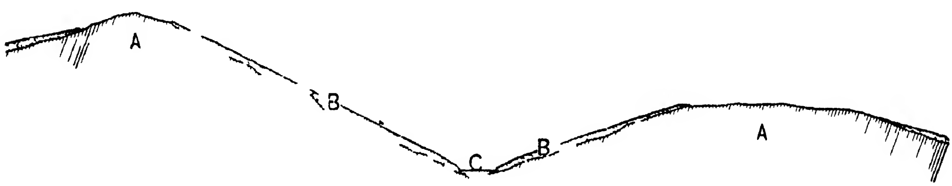


Diagram Showing Conditions of Torrent Valley in which Alluvial Soils are Forming

A A Bed-rock B B Detritus slowly creeping towards stream C Torrent bed

when we come to study them in an ampler field. The principal difficulty arising from such an illustration is that it leaves out of mind all circumstances of time which have to be considered when we endeavor to follow the great lines of the earth's history. The soils of the earth's surface must be regarded as those portions of its hard rock which are on their way, after undergoing a certain amount of destructive action, back into the sea whence they came, and where they are in turn to be employed once again in constructive work.

To see this process in a large way the reader should betake himself, at least in imagination, to the upper portions of a considerable mountain district on which the work of soil-

making is going on with great rapidity, though the product of the work may not remain upon their steep and storm-swept surfaces. On rocky declivities we find a number of agents at work tending to disrupt the solid earth. We have already noted the fact which arises from the slight impact of the rain-drop. This effect is trifling in any shower, but accumulated through the ages it becomes an agent of considerable importance. Along with the rain comes the lightning, which, striking upon the dry rocks of the mountain-peaks, often effects a considerable rending of their masses. Here, too, gravity operates more effectively than it does on the lower lands where the surface of the bed-rock is nearly level. Gravitation itself does nothing to promote disintegration as long as the surface is level, but as the slopes of the hills increase, the effect of this force augments in a very rapid manner. When the slopes exceed forty degrees in declivity, some of the dislocated fragments are almost certain to roll down them in a violent way and to be broken by the shocks which they receive in their downward movement. Wherever the bare rocks of steep mountain-sides are exposed, they are assailed by frosts. All rocks whatsoever are penetrated by lines of fracture which are termed joints. Every quarry exhibits these joints, indeed it is only where a rock is advantageously jointed that it can be used at all by the quarrymen. These joints are in their original form only incipient lines of fracture; they scarcely appear to the eye before that peculiar attraction known as capillarity draws water with great energy into them. A familiar illustration of this capillary action is seen in cases where dry wood becomes wet and expands with great violence. It is possible to split stones by driving wooden wedges into drilled crevices and wetting them

with water. The curious tension which may be put upon a rope by wetting it is due to the energy with which the water is drawn into the spaces between its fibres. This capillarity in itself serves, in a measure, to rend the rocks, but it works more efficiently in this direction by drawing water between the plates of the rock, where, when it becomes frozen, it may expand and operate, within narrow limits, with all the energy of fired gunpowder. Each winter's freezing pushing the plates of the rocks a little distance apart, small wedges of the material also loosened by frost drop into the crevice, and when the ice which led to the expansion melts away, the sides of the opening can no longer come together. The next winter this is repeated, and so in the course of time the mass is urged beyond its supports and descends as a rock avalanche. These joint lines are also the channels by which ordinary chemical decay penetrates into the rock. The water affords oxygen which by promoting decomposition leads to the breaking up of the stone. If there be iron in the rock in the form of pyrite or magnetite, it may become oxidized and by its expansion produce a thrust tending to disrupt the masses. If there be felspar in the mass, this may be converted into kaoline and also expand by the change. There are many other actions brought about by chemical decay, operating to deprive the rock of its coherence and to push it out of its original resting-place.

The roots of trees are also agents of great power acting with all the energy of wedges to drive the stones asunder. Again, when trees are overturned, these roots which have penetrated between the crevices of the stones often lift considerable masses out of their beds, and place them in positions where when the enveloping roots decay they will be free to

tumble down the slope. When steep mountain-sides are shaken by a violent earthquake, great masses are often detached from their sides and descend as avalanches to the lower lands. Again, when the mountains are snow-covered as most mountains are in winter time, the incoherent snow often precipitates itself into the valleys below. At its source the avalanche is of a trifling nature ; the snow light as feathers starts down the slope ; when it has moved a little ways, the pressure of the part which is in motion upon the lower-lying snow causes the mass to become compact, and in a short time the avalanche is more like a mass of white ice than the snow in which its movement originated. Gaining depth and momentum as it descends, the stream soon begins to rend away the loose materials of the rock surface over which it pours, and in the course of half a mile of journey it often comes about that a quarter or more of the avalanche is made up of stones and mud. The frozen water in time melts away from the heap which has been precipitated into the valley, but the rocky matter remains to be dealt with by the stream of the torrent-bed in which it lies.

The most evident effect which the observer perceives when he studies the above noted processes is that stones are thus brought down from their lodgments in the cliffs and on the steep slopes of the mountains, to the beds of the torrents (see chapter on Rivers and Valleys, page 143). A very little observation will show him that in the torrent-bed, the rocks are rapidly broken to pieces by being driven against each other and pounded against the sides of the mountain as the brook hurries them downward to the low-lands. There is a less evident but still important influence, which is brought about by this movement of rocks down the

mountain-side. If we take a pebble or any other mass of rock which has long lain upon the surface of the earth, we perceive that it has decayed on its outer surface: even if the decay be not evident to the naked eye, we can see it by scratching the surface with a knife; breaking the pebble we find that its interior parts resist the action of the knife more vigorously than does its outer part. The fact is that every such pebble is undergoing a process of decay from the attack of the atmospheric agents. The proportion of the decay in any given period depends upon the size of the fragment. It is relatively greater, the smaller the mass is.

On the tolerably smooth rock such as we may find in many mountain-peaks, atmospheric decay has a very small surface to operate upon. It works along on the exposed face of the rock and on the open joints which extend for a certain distance below that surface. If we assume that these joints cross each other at distances of three feet apart, and that there is a plane of jointing parallel to the surface, we assume that the mass is divided into cubes of a yard in dimension, and that they each expose therefore fifty-four square feet to the agents of decay. If we break the mass into fragments each a cubic foot in size, we increase the surface accessible to erosion to one hundred and sixty-two square feet. If we break it still further into cubes an inch in diameter, the surface exposed to decay increases to over a thousand square feet of area; or, in other words, the rate at which the material breaks into the finely divided matter we term soil, is increased more than one-hundred-fold of what it was when the rock was in masses three feet in diameter. Now, most rocks while they are violently precipitated down a mountain-side undergo a process of fracture which in many cases may

serve to break the mass into fine bits. This is especially the case with materials which have for a long time remained exposed to the action of the weather. Thus in a moment's journey in the avalanche of snow or stones a mass of material, as great as the soil on a considerable field, maybe, has advanced a great ways towards the degree of comminution necessary for its conversion into fertile earth.

Age after age these mountain-ridges, which rise under the impulse of those deep-seated forces which crumple the rocks, are constantly yielding great supplies of *débris* to the torrents. The ordinary visitor to the highlands has little opportunity of witnessing this process, for the reason that it usually goes on in seasons when travellers do not resort to the mountain heights. Such rock-falls commonly occur in the early spring, when the snows are melting and the rocks released from their bondage in the ice, or they come in times of great rain, when they are equally likely to escape observation. Every one who has spent much time in Alpine heights has had occasion to remark such falls, and may often have narrowly escaped their dangers. Most commonly, these tumbles are of small fragments. A bit of stone a few inches in diameter frequently skips from some cliff and goes bounding down the slope until it has attained the torrent-bed, or until it is shivered into fine fragments. Occasionally, however, vast rock-falls have been observed in movement, and every Alpine valley abounds in heaps of stone which the trained eye recognizes, despite the vegetation which mantles them, as the remainders of such great accidents.

For the reason that the Alps of Switzerland are the most inhabited of any great mountains in the world, we have from them the best records of such catastrophes, which have often

proved singularly destructive to life and property. A number of these accidents have occurred in modern times. Of these, one of the most picturesque occurred in the last century, in the high circus-shaped valley which lies at the foot of the Diablerets Mountains. This elevated and beautiful valley is of such difficult access and at the same time affords such good pasturage that the people of the villages below have, at very great cost, hewn pathways in the precipices to gain access to it for their flocks and herds. Forming the north side of the Diablerets Mountain is the great precipice, on the summit of which stand several great mountain-peaks. The beds of rock

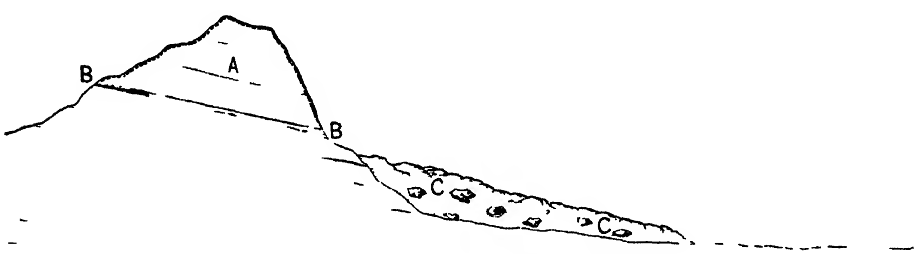


Diagram Showing Conditions of a Great Landslide

A, Mountain of stratified rock. B, B, Clay layer C, C, Position of *débris* after movement

composing these masses have a general inclination towards the valley. Although the most of the layers of rock are of very hard material, there are some which are permeable to water. The result is that, from time to time in the past, vast masses of cliff have been detached and hurled into the valley below, where their course of ruin can be traced across the grassy slope by the confused heaps of stone.

The greatest of these accidents and the last came in the night time, when one of the largest of the peaks which crowned the great precipice leaped from its base and poured downwards in a vast mass of crumbling stone, which formed an avalanche having an average width of path of more than a third of a

mile, and extended to a distance of about three miles from the base of the mountain. Its way lay through the most fertile portion of the amphitheatre, in which were many of those shelters in which the lonely cattle-herders of the valley protect themselves and their milch cows. As the accident happened after sunset, a score or more of the herdsmen were overwhelmed along with their cattle. There is a story told in connection with this accident which has a peculiarly pathetic side. One of these shelters, which housed a herdsman and his herd, was not crushed in by the avalanche. Its stout walls and strong roof, built to resist great falls of snow, remained intact Finding himself thus imprisoned, the unhappy man labored in the darkness in making a burrow upward towards the light of day. He fed his cattle with the stores of food which the place contained, watered them from a stream which trickled into the shelter, and slowly heaped the earth from his tunnel into all the spare room which the building afforded. At length, after nearly a month of toil in the darkness, he escaped to the light of day. Pale and emaciated from his long imprisonment and arduous labor, he hastened back to his native village, where, according to the story, he was received as one who had returned from the land of spirits. He was met not with joy, but by the priest, who, with "book, bell, and candle," exorcised him as an evil spirit. His people denied him his accustomed place, and he wandered forth, no one knows where. It was only after the tunnel which he had made was discovered that his friends believed that they had seen something more substantial than his spectre.

On the northern side of the Alps, in the canton of Schwyz, near the shores of Lake Lucerne, another great fall took place in the early part of this century. Like the preceding, it was

caused by a bed of clay lying underneath the mountain-peak, which stratum became softened by penetrating water and so enabled the overlying mass to launch itself into the valley below. A considerable lake was formed by the avalanche of waste which remains visible to this day. The strong wind arising from the compression of the air in front of the downward rush of earth and stones, which is always a conspicuous feature in these great mountain falls, was especially noted in this catastrophe. It was related to me by the son of one of the survivors of this accident, that his father, in company with five other young men, was walking upon the road in the path of this avalanche. The companions were going two by two, with considerable intervals between them. The two most in advance disappeared beneath the moving mass. Two others, who were not overwhelmed by the avalanche, were blown to a considerable distance and their clothing partly stripped from their bodies, but they escaped with their lives. Those furthest away were thrown over by the wind of the avalanche, but not seriously hurt.

At various times within the historic period, villages have been buried beneath these falls. Those of my readers who may have journeyed afoot up the Rhone valley, between Villeneuve and Aigle, may have noticed on the left hand of the road the little village of Yvorgne, famous for its excellent vineyards which afford the best white wine of Switzerland. A part of these vineyards lie upon the slope formed by a great mountain fall which occurred in the last century. They owe their goodness, it may be, to the open soil formed by the powdered stone produced in the catastrophe. The ruins of the old village are said to lie beneath them, and from time to time the present dwellers on the site fancy they hear the bell of the

buried church ringing in the under ground. Accidents of this description, which occur in all mountain countries from time to time, are most common in regions where the peaks are steep. They also happen even where the declivities are of moderate slope; conspicuous cases of this nature are common in all parts of the Appalachian range. Whoever has visited the White Mountains has noticed long scars upon their sides caused by the so-called slides which occur there. The best known of these happened in the Willey Notch in 1821, when, from a steep mountain slide on the north of the valley, after a period of long-continued rain, a great mass of rock and earth detached itself from its place a thousand feet above the valley, and poured as an avalanche to the base. An unhappy family, whose dwelling lay directly beneath the seat of the accident, fled at the sound of its coming. The dwelling they occupied was left unharmed, but they were caught in their flight by the descending mass and overwhelmed.

Although these incidents are of a picturesque nature and serve but inadequately to set forth the character of the destruction which these avalanches bring about, the reader may gain from them some conception of how far gravitation gives to the mountain-torrents a supply of *débris* which may be ground up by their waters and sent downwards to the lowlands. But for such continuous provisions of detrital material, these torrents could not do their appointed work. The most of the stony matter which we find in their beds has come to them by the action of gravity operating on steep slopes. Not only do the mountains send down an occasional supply of waste in these avalanches, but all the stones which lie upon the slopes are slowly creeping towards the stream-beds. Each winter's frost expands the mass and causes it to move a little way downward.

It may be that the onward motion is only a small fraction of an inch per year, but in the ages this is sufficient to maintain a supply of loose stony material in the torrent-bed, which is ground up in times of flood. Where a torrent is insufficiently supplied with stony fragments to maintain a covering on its bed, it eats into that bed, deepens its channel, and so adds to

View of Stream at Point where it Passes from Torrent Section to River Terraces Beginning to Form (Eastern Kentucky.)

the steepness of the slope which leads towards its waters. By steepening the slope it increases the amount of material which is fed into it. In this way almost every brook has come to a balanced state in relation to the supply of *débris* afforded by the fields on either side of it. Where the material comes more rapidly to its bed than its waters can grind it up and remove it, it ceases to wear downwards and remains on the same level until the sides of the valley have somewhat diminished their declivity by the process of erosion; where, as before noted, the

supply of detritus is insufficient, the deepening of the gorge soon assures an increased precipitation of waste into its bed.

A small portion of the detrital matter ground up in the beds of the torrents is carried directly downward to the sea; by far the greater part of the pulverized stone finds its way in the lowlands on to the sides of the river, and forms the extensive alluvial plains which constitute a very large part of the more fertile soils in the world. Thus along the banks of the Mississippi and its innumerable tributaries we find an area of detrital plains composed of material ground up in the torrents of the hills and mountains of the head-waters of that stream amounting, perhaps, to more than fifty thousand square miles. As soon as a mountain brook escapes from its steep descending gorge into the lower plain region, it begins to form such an alluvial terrace. In each flood time the silt-laden waters spread over the surface of this terrace, contributing a layer of fine mud, rich in the possibilities of nutrition for plants. The larger the stream, the wider this plain. Where the brook first emerges upon the lowlands its alluvial border lands may be only a few score feet across. When it has become what we term a river, the alluvial deposit in most cases is many times the width of the stream itself. Gradually widening, this terrace may, as in the lower regions of the Mississippi, attain a width of a score of miles on either side of the stream-bed. At first this alluvial plain rises but a little way above the ordinary height of the stream, but each successive flood adds a little to the matter upon it and so increases its height. At the same time, provided the surface of the land does not change its level in relation to the sea, the bed of the river is constantly working downward; and so it comes about that the floods visit the top of the terrace more and more rarely; at last they cease even in the times of greatest inundation

to attain to its level. Finally the terrace may be left high up above the stream in the fashion of those benches which we find along so many of our rivers. Those in the Ashuelot valley, a tributary of the Connecticut, which are represented in the cut, will serve to illustrate the position of these ancient alluvial terraces in relation to the present stream.

At the mouth of the river where its current is checked by contact with the sea, and where the salt water operates to hasten the precipitation of these sediments, the alluvial plains spread out rapidly on either side of its course. In this and the lowermost portion of the alluvial plains the course of the

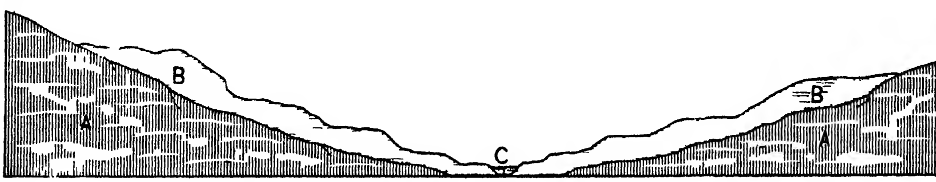


Diagram Showing Portion of Alluvial Terraces in a River Valley

A, A, Bed-rock. B, B, Alluvial terraces. C, River bed.

stream becomes extremely vagarious, and the variety of accidents serve to impel it into new channels. On the side of each of these new-made ways it builds broad plains, and so by its wanderings vastly widens the area occupied by deposits of this nature. At first these alluvial plains are very swampy, but as the continents normally tend to a steadfast growth upward, in most cases they become excellent soils. Even where the uplift of the continent fails to bring them to a sufficient height to fit them for the uses of man, it is often possible by a system of artificial drainage to win them to agriculture. Provided the inundations which the river brings over the plains do not occur during the tillage season, they may be used for crops without any engineering defences whatsoever. The region about the mouth of the Nile is a capital instance of those influences in

which the river floods are so ordered as to help rather than hinder the tillage of the land. The delta of the Rhine in which lies the greater part of the Netherlands is an example of what engineering skill can do to win the site for a rich state from the morasses about a stream's mouth.

We thus see that normally along this great river we have a region of soils extending beside the paths of the branched stream from its mouth to the foot of the torrents in which a material of the alluvial plains was made. Let us now notice the peculiar advantages connected with this class of alluvial soils. In the first place, as may be readily apprehended from the foregoing account of their formation, these soils are extremely deep and are in most cases practically of inexhaustible fertility. If we take an ordinary specimen of such soils, and examine it closely with the eye or better still with a powerful magnifying-glass, we see that it is composed of very small fragments of stone finely divided by the running water and by grinding between the pebbles of a torrent-bed, and furthermore that each of these tiny bits is more or less completely decayed. Looking closely we may often see that the little grain of rock is wrapped around by the fibres or rootlets of the plants, showing us clearly that these plants are able to extract nutriment from it. Between these fine grains of decayed rock we observe more or less organic waste,—small particles of decayed vegetable matter, or it may be occasionally a tiny fragment of a fresh-water shell which has been ground up in the same mill of the stream and made to contribute nutriment to the soil. Even the most reckless agriculture, though it may remove the fertile elements from the superficial layers of an alluvial terrace, cannot destroy its fertility as long as the stream can send these occasional floods over the surface. For each of these

floods, when the waters are checked in their motion as they are when spread out as a thin layer over the plain, sends down on to the soil a coating, it may be several inches in thickness, of fine sediment, alike in fertility to that possessed by the soil before it was touched by man.

We thus see that the system of erosion which goes on in the highlands provides the lowlands with one class of peculiarly fertile soils. There are certain other advantages connected with these soils of the alluvial plain which deserve note. They are always singularly open to the plough, there are usually no stones in them such as made the winning of the stubborn fields of New England to agriculture a matter of the greatest difficulty. Moreover, their products are in most cases adjacent to navigable water-ways, and may thus enter readily into the paths of commerce.

It is, therefore, not surprising that nearly all the first seats of agriculture were along the banks of rivers, and that to this day the most fertile fields and the most prosperous agriculture lie upon their borders. These alluvial plains gave the early races, with their simple primitive means of agriculture, an opportunity of passing from the necessarily savage state of the huntsman to the more affirmed relations to the earth which agriculture brings about. They are thus the cradles of civilization, as they remain to this day the principal seats of culture and prosperity.

A second class of soils is found on the surfaces beyond the reach of the silt-laden waters in the time of flood, such as we may observe over the larger part of any ordinary valley which lies beyond the field possessed by the continental glaciers of the last ice age. On these surfaces the declivity is too small to help gravitation to urge detrital matter down the slope and

into the mill of the stream. No careful study has as yet been made concerning the slope on which this downward motion of the rocky waste towards the streams takes place. From some observations which I have made in the valley of the Ohio I am inclined to believe that wherever the slope of the surface exceeds ten degrees in declivity the winter frosts operate with a certain measure of effect to bring the detritus worn away from the rocky slopes into the control of the torrents, but that where the declivity is less considerable the amount of such movement is so small that it may be left out of consideration. Over the most of a river basin such as that of the Ohio the slopes of the surface do not exceed five degrees of inclination, and on such areas the wasting of the soil is mainly brought about by the direct cutting action of the streamlets, or by the percolation of the waters through the mass of earth and the rocks beneath it. These percolating waters dissolve a portion of the material, and bear it away to the streams in a state of complete solution. Therefore on all those uplands of gentle slope which are unvisited by flood waters, the soil is immediately derived from the rocks beneath its surface.

The process by which these soils of immediate derivation are formed is very interesting. To see its nature we must make a section extending from the surface downward into the solid rocks below. It is best we should make this section at two different points: at one in a virgin forest which has not yet felt the hand of man; in the other, in an old field adjoining such forest, where the plough and the other destructive instruments of agriculture have brought about their normal effects. In our section through soil beneath a forest we find first a thick layer often a foot or two in depth composed altogether of decayed vegetable matter. The greater part of this

material in the level next the air is composed of what we recognize at once as decayed leaves, branches and trunks of trees. As we go downward this remainder of vegetable structure in the mass slowly disappears, and at the base we have a very fine earthy or loamy matter the grains of which are almost impalpably small, hardly gritting between the teeth when we test it in that manner. This material is mainly composed of the ash of woody fibres, such ash as we find in the fireplace where wood is burned, only with the greater portion of the alkaline matter leached away by the rain. From this upper layer which is the product of vegetable matter falling to the surface, we pass rather suddenly into the portion of the soil where vegetable matter also abounds but where this material is mainly derived from the decayed roots of trees and other plants which penetrate into the earth.

In many cases the division between what we may call the aërial layer of the soil or that made by the falling of vegetable matter, and the true subterranean soil, is indistinct. There are many accidents which serve to confuse the two layers, the principal of which is the overturning of trees. Almost all forests are liable to occasional hurricanes which lay the trees over thousands of acres of area in a great swath, as the scythe fells the grass. A large part of these trees, owing to their strong trunks, do not break off, but uproot, lifting a great sheet of earth into a vertical position. As the dead tree decays, this overturned earth tumbles back in confusion upon the surface, and so in course of time the trees over a wide area may be so frequently uprooted that something like a ploughing of the soil is accomplished, the overturning action extending to an even greater depth than is accomplished by the work of our ordinary instruments of tillage. Then again

the animals of a wood bring about a vast overturning of the soil. Darwin has shown that our earth-worms take from the depth and bring to the surface of the soil a very large amount of material, so that in the course of a few centuries the soil is to a great extent overturned by their action. Our ants, as my own observations have shown, are in many of our soils, particularly those of a sandy nature, even more effective agents in overturning the earth than the worms. A large part of the sandy fields in eastern Massachusetts are curiously tilled by these animals. In the course of a single season they may bring to the surface of the soil as much as is equivalent to a layer of one-fourth of an inch in depth over wide areas. In a less conspicuous but still important way our ordinary underground mammals, the gophers, groundhogs, moles, field mice, and sundry other animals, are engaged in the same work of commingling the upper and lower layers of the soil in a way which greatly promotes the formation of the deposit and its fitness for the needs of the plants. The depth of this naturally tilled area of the soil varies greatly, but in general it extends to more than a foot below the base of what we may term the aërial stratum, and the whole of the section in which the natural overturning agents have commingled the soil materials is often as much as three feet in thickness. The thickness of this tillable or more nutritious stratum of the earth varies according to circumstances which we have shortly hereafter to note.

Below the level of what is commonly termed soil we pass into a section which usually receives the name of sub-soil. The striking difference between the soil proper and sub-soil consists first in the degree of compaction of the material in the two layers, and second in the extent to which the earth is com-

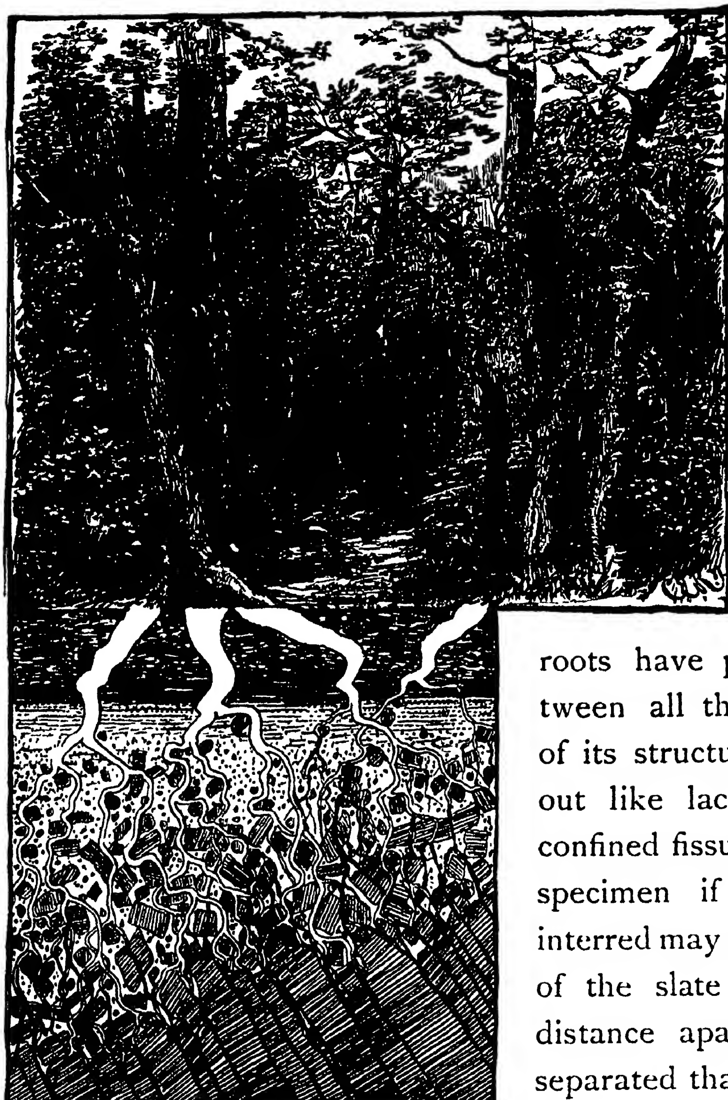
mingled with fragments which have become separated from the subjacent rock. The difference in the compaction of these two layers is easily explained. It is manifestly due to three classes of actions. First to the overturning of the soil brought about as before described by the uprooting of trees and by the burrowing work of animals; it is also in a measure due to the effect of the roots of plants. These roots first extending in the form of delicate fibres in the soil rapidly expand in their growth, and press the grains of the earth aside. Finally when the roots decay they leave spaces which often remain for a long time as hollow tubes but which gradually become filled with substances washed into them. Then again water penetrating through the principal part of the earthy matter bears away in solution a considerable amount of solid matter, leaving the spaces which it occupied, vacant. Last of all, the frost, if it enters the earth as it often does to considerable depths, expands, pushing the grains upward with great energy. When the water becomes again molten, the weight of the mass is not sufficient to return it to the original state of compaction. In the sub-soil most of these agents tending to give the mass an open structure do not act. It therefore remains in a more solid form.

The process of formation of sub-soil which in time is to be merged in the soil proper is somewhat various. In the main, the work is done by the downward penetration of water. In all cases this penetrating water leads in the work of converting the underlying rock into soil. As we before noted, pure water has a very slight effect in dissolving stony matter, but as the rain falls upon the forest bed it enters into the uppermost zone of the soil where it passes through a great quantity of decaying wood. A small portion of the water gives up its oxygen to

convert the carbon of the wood into carbonic-acid gas; another part charged with this carbonic acid penetrates downward to the deeper earth. By virtue of the dissolved gaseous material, combined oxygen and carbon, the water gains an enormous increase of this solvent power on rocks: as we have seen, the increment may be as much as fifty-fold. Passing through the soil these carbonated waters come in contact with the subjacent rocks, they penetrate into every crevice and open up by their dissolving action innumerable channels which lead down indefinitely into the depths. If the rock be a limestone, this under-channelling takes place with great rapidity and momentous effects, producing great caverns in the underground regions. By this solvent action a portion of the underlying rock is directly converted into soil.

Wherever a crevice in the rock is made, the roots of certain trees, especially those which have what we call tap-roots, are apt to penetrate. After a lodgment is effected in the cranny the root expands with its growth, rends the stones apart, and as may be seen in many cases lifts them above their bedding into the plane of the sub-soil. The tap-root trees, such as our hickories and many other forest plants, appear to rejoice in an opportunity to invade these subterranean crevices. It is certain that they find there a fresh feeding ground, one that has not already been searched through and through by other plants as has the upper portion of the solid bed. Thus it comes about that the roots of the trees are natural ploughs, or rather we should say quarry tools, operating ceaselessly to rend away the superficial portions of the rocks, and to bring them into the soil plane. The work is not completed when the mass has been separated from the solid earth, for the enveloping roots project their fibrils into

every crevice of the fragment and so divide again and again the mass until it is reduced to the finest grains into which it is divisible. This process is best seen where a slaty rock is subjected to such action. We would often find in a bit of slate which is taken from such a subsoil, that the roots have penetrated between all the thni laminæ of its structure and spread out like lace-work in the confined fissures. Another specimen if carefully disinterred may show the flakes of the slate lying a little distance apart, but so far separated that they fall into bits on being



Section through Forest Mould Soil and Sub-soil, Showing Action of Roots on Bed Rock.

We have spoken of the process of soil-making as perfectly continuous. The reader may well ask why it should be continuous—why might not the soil attain a certain depth and then afterwards remain

permanently, or at least with very slight changes, in its required condition? The answer to this is simple; it needs hardly to be made, save that from it we may obtain an important lesson as to the earth's history. All the soil covering of the earth is constantly wasting by the leaching out of these materials. Although the water which flows from a forest-clad area may appear to contain no sediments, it is always considerably charged with mineral matter in the state of complete solution dissolved as is sugar in water. We find this sediment if we boil away the water of the clearest spring to a point of complete evaporation; there is always a little sediment left on the bottom of the vessel which is composed of material a part of which has wasted from the soil through which the water flowed. It is the accumulation of this matter which forms the coating on the bottom of an ordinary tea-kettle, though that vessel may be supplied by water from the purest spring. In general this waste of matter is most considerable in the upper portions of the soil, for the reason that in that level the grains of rock are of smaller size than in the lower parts. We have already noted the fact that the smaller a bit of rock, the larger its surface in proportion to its mass, and so, other things being equal, the finer grained a soil is, the more rapidly it yields material in the condition of solution to the water which passes by it.

Thus we see that the upper surface of a soil is always sinking downwards, and the lower surface is also going nearer the centre of the earth. Over the greater portion of the earth's surface it is evident that the adjustment between the rate of downward going in these two surfaces is singularly well accomplished. It is easy to see that where the upper surface works downward by the process of decay more rapidly than

the lower portion penetrates into the earth, we should in time have no soil whatever. On the other hand, where the lower surface of the soil advances towards the earth's interior more rapidly than the upper part, that soil would have an indefinite and, in most cases, a very great depth. It is a familiar fact that, in a general way, the soils on the earth's surface are rarely less than a foot in depth and seldom exceed four times that thickness. This shows us that there is some adjustment of relations between the conditions which lead to the descent of these two forces.

This interesting adjustment is doubtless accomplished in the main through the action of the roots themselves. Where the soil is thin they are forced to take every opportunity of penetrating into underlying rock, and so greatly aid in rending it. Where, however, the lower rock decays rapidly without the intervention of root action, they satisfy their needs in the thicker soil which forms upon it. Moreover, the deeper the soil the more the dissolving power of the water is expended in the upper part of it. Thus the balance is effected which keeps the soil generally thin enough for the roots of the plants which need the most nutrition to push downward into the earth to the measure required by their necessities, and at the same time the deposit rarely becomes so thin as to make vegetation impossible. This balance, which retains soils within a narrow limit of depth, is of importance; for, if the deposit were indefinitely deep, there would be the risk that the upper portions might become exhausted by the downward leaching of the soluble materials to a degree that would be dangerous to plant life.

The reader is now prepared to understand that the soil-coating on the surface of our lands represents the residue of

material which has remained above the level of the sea during a very long period of atmospheric erosion. Any one cubic foot of soil taken from the region of this continent south of the glacial belt—as, for instance, in the valley of the Tennessee River—is likely to contain in it bits of rocky matter from strata which have long disappeared from the region in which we find them. A single cubic foot of material may represent the waste of perhaps a thousand feet of rocks which have gone from the land to the sea. We can often prove this proposition by a close inspection of the material. Thus, in the head waters of the Green River, in Kentucky, I have found in the soil of the hill-tops small silicified fossils, which were originally bedded in rocks that lay several hundred feet above the present level of the surface. These rocks have entirely gone away to the alluvial plains below, or to the sea, but these resisting bits have followed the descending soil downward, remaining as witnesses of former geological conditions. We must, therefore, picture to ourselves the soil-coating of the earth as slowly descending from great heights towards the level of the sea. But for the fact that the continents are constantly growing upwards, all these soil-covered districts would in the end be brought too near the level of the ocean surface and converted in the foundations of great morasses.

A third group of soils is found in regions which have recently been visited by extensive glaciers. We have already seen that where a region is exposed to the normal conditions of the atmosphere, its soil-coating is divided into two distinct districts, that of alluvial lands in which the soil is derived from a considerable distance up the stream on which it borders, and those which lie remote from the streams where the soil is immediately derived from the rocks on which it lies. In the

glaciated districts we have yet another condition of affairs. Except so far as the streams recently released from the bondage of ice have constructed alluvial plains along their margins, the whole of the glaciated district has soils which have neither been derived from the rocks immediately beneath nor borne to their position by ordinary rivers, but which have a third method of origin.

The broad continental ice sheet with its occasional underrunning streams of water, streams which follow no particular channel but sweep over the surface of the land, wears away a vast quantity of rock matter. A portion of this material is borne to the margin of the glacier by its forward movement, and is there accumulated in the form of moraines, vast heaps of confused materials any cubic foot of which may contain fragments which have come from regions very far apart from each other. When the ice melts away, the stony matter, pebbles, sand, and mud which was enveloped in its mass, drops upon the surface and forms a detrital coating, where also lie together materials which come from widely separated fields. When the ice goes off, the plants suited to the conditions seize upon the desert of broken rocks as they do upon all unpossessed surfaces of the dry land, save the deserts. Very quickly, far more quickly than indeed the process takes place on an unbroken rock, such as a quarry, this detrital matter is brought into the state of soil. The process is aided by the fact that a very large amount of the rocky matter is in a finely divided state. These soils not only speedily form, but have a certain measure of fertility; the trouble with them is that they are often composed to a great extent of large stones so that the actual amount of material devoted for plant use is relatively small. Thus in many stubborn New England fields which

have given crops of corn for two hundred years, scantily but uniformly, the actual soil is extremely rich, but the quantity of it when we take away the pebbles too large to be counted as a valuable element in the soil, is very inconsiderable.

Operating on the glacial soil the agents of decay work to great advantage. The deposit is generally thick, and there is no question of disrupting the bed-rock which is often a slow process. In the glacial districts this work was done during the ice time. Therefore, apart from their stony character, the ordinary glacial soils, or at least those formed of the material left on the surface as the ice melted away, are commonly of an excellent nature. The moraines properly so called, the heaps left near the ice front as they are now left by the Swiss glaciers, are generally unfertile for the reason that, owing to the circumstances of their accumulation, they have been washed over by streams of water which have borne away the valuable clay which is the finest element of a soil, leaving only the sand and boulders.

The fertility of our soils depends upon the chemical character of the rocks which by their decay afford these materials. If the soil is derived from rocks which by their composition afford a wide range of substances, the soil is sure to have a good measure of fertility, unless by some chance it is too fine grained to retain the water necessary for the plants or to give access to the air which has to penetrate it in order to bring material into the condition for the use of vegetation.

It is an interesting fact to note that soils depend for their fertility to a singularly great degree upon the materials placed in the underlying original rocks by the action of life which has existed in former geological ages. This fact is particularly manifest in our stratified rocks, but in those of a crystalline

nature such as mica schists, or even in rocks which have advanced further towards the crystalline condition, the dependence on ancient animals and plants is also manifested. Thus in the famous "blue grass" region of Kentucky, an area of ten thousand square miles, where the land has a surprising fertility and endurance for tillage, we find this fertility to be due to the presence in the underlying rock of abundant remains of animals. Certain small shells and yet more minute crustaceans have power of taking from their food a portion of limey phosphate which they build into their skeletons; when they die these solid parts pass into the strata which are accumulating on the sea floor. In this manner, in the above-named region, a number of beds have been formed not usually more than a few inches in thickness, which by their decay afford the soil an invaluable resource of phosphatic matter. This is made avail of in the growth of grasses and grains; each grain of wheat returns to the organic state matter which has been stored away in the fossilized bodies of minute creatures ever since the Silurian age. We see in this way how the life of one geological period helps the creatures of subsequent ages.

The problem of furnishing phosphatic matter to our soils is the gravest of all which man has to meet, unless it be that of preserving the soil itself from destruction. To obtain food for himself and for his domesticated animals, man is compelled to tax the phosphatic resources of every field in which he grows grains of any description. In certain limited areas as, for instance, those above noted in Kentucky, the sub-soil wastes with such rapidity, that it is easy to maintain the quality of the soil from generation to generation without the artificial replacement of this precious material, but in by far the greater number of cases it is necessary to effect this replacement by some form of

manuring. Fortunately for the interests of agriculture, certain deposits contain a very large amount of phosphatic matter which is yielded to the miners' art.

The discovery of these deposits and their adaptation to the work of restoring phosphorus to our soil constitutes, perhaps, the greatest advance in modern agriculture. Through this art we see our way to resist the exhaustion of our soils in an effective manner for centuries to come. Within twenty-five years this industry has become so rapidly developed, that at the present, artificial phosphatic manures are produced in this country at an annual cost of more than thirty million dollars; and it is likely that before the end of the century it will become one of the most considerable of the arts in all countries where agriculture has attained the position of a science. All these concentrated phosphates which are mined for agricultural purposes are essentially like those which naturally contribute to the fertility of soils, the only difference being, that in the mined deposits the accumulations are more extensive than those which naturally contribute to the soil's fertility.

We have incidentally spoken of the effect on soil due to the penetration of the atmosphere into its depths. In that state of nature, the machinery to accomplish this intermixture of the air with the soil is brought about by a variety of actions. The overturning of the soil, accomplished by the blowing down of trees and by the action of their roots which form cavities when they decay, into which they penetrate, is an important part of this machinery. The action of burrowing animals, which, as we have seen, bring about a constant overturning of the soil, is another means whereby this aëration is effected. Yet another method is found in the constant downward penetration of water into the soil. This water takes with

it a certain amount of air, and, as it sinks into the crevices, draws in behind it a considerable amount of this material. In these several ways the oxygen of the atmosphere, which brings about the decay of the soil and its preparation for the uses of the plant, is constantly carried into the under earth. It is one of the difficulties attendant on the artificial overturning of the soil by the plough, that the measure of this penetration of the air is considerably reduced. In the single overturning of the soil, which is accomplished in the seasons of the plough, a certain amount of air is buried in the soil, and the subsequent processes of tillage effect the same result in a moderate degree. There can be no question that the amount of air introduced by these processes in the uppermost portion of the soil is more considerable than it is in the state of nature; but although the upper few inches of the soil is well aërated by our artificial processes, the lower part, the sub-soil of the section in which very important work is done, is practically excluded from contact with the air by our process of tillage. The roots no longer penetrate deeply, and the greater part of the burrowing animals are driven away. Moreover, the foot of the plough, which has to press heavily upon the sub-soil in order to overturn the earth of the furrow, soon smears and compacts the earth at a certain depth into a hard layer which excludes the air and to a certain extent even the water from the lower level.

The most needed correction in our ordinary methods of tillage consists in devices to avoid these difficulties. Where the tillage is by the means of the spade, these evils are most effectively avoided, for with that tool there is no tendency unduly to compact the sub-soil. The greatest need of our modern agriculture is for some instrument which will overturn

the soil in a cheap manner in the way in which it is overturned by the spade. It seems as though there should be no serious mechanical difficulty in producing such a device, and we may hope that when people come to see the singularly destructive action of the plough it may be replaced by some such device. At present there are but two methods of overcoming this evil. One is by artificial drains laid at considerable depths below the surface. These drains by permitting the rain-water to penetrate to considerable depths enable it to convey air into the sub-soil. Something also is accomplished by means of sub-soil ploughs which tear up the lower layer. This is a clumsy and only moderately effective device for avoiding the evils of ordinary ploughing; it transfers the contact and action of the plough to a lower level of soil. Unless the process is well managed, the sub-soil plough tends to bring to the surface the lower materials of the soil layer before the process of preparation for the uses of plants has advanced to the point where they can afford much nutrition.

Although the plough is necessarily a disastrous instrument in its effect on the soil, the evils which arise from its use increase very rapidly as the depth to which the instrument overturns the ground diminishes. In our American agriculture the plough is generally so managed as to limit the penetration of the roots to a depth of eight inches or less, making below that level the hard-pan before described. The result is that in times of heavy rain, the upper portion of the soil receives more water than it can store; it becomes a mere slush which tends to slide down the slopes of even a slight declivity. If the plough effected its work to the depth of a foot or more, the effect on the soil would be much less disastrous. If we are to preserve the surface of the earth in fit condition for the gener-

ations to come, we must either by law or by public opinion forbid such destructive management of our soils.

One other statement needs to be made in order to set the soil problem clearly before the mind of the reader. In any cubic foot of earth, however well fitted by nature or by tillage for the uses of plants, the quantity of material which at any one time is ready for assimilation by the roots is very small. It probably in most cases does not exceed one-thousandth of the whole mass. The essential peculiarity of this soluble part of the soil is that it is ready under the influence of plant action to pass into the state of solution and be absorbed into the roots. If not so absorbed this soluble material readily enters into the general mass of water and soil, and so escapes with that water to the stream and back into the sea whence it came into the structure of the rocks. The great art of tillage, the art through which in time we may expect much help in the conservation of our soils, is to regulate the amount of this material which year by year offers itself to the uses of plants, and to avoid as far as may be the deportation of this precious substance by the underground waters.

It now seems likely, though as yet far from being demonstrated, that the last stages of the process by which the lime-phosphate and certain other materials used by plants are brought into a state in which the roots can appropriate them are accomplished through the aid of ferments which are at work in the soil. These ferments consist of organic forms of a very lowly organization, allied to the mould commonly seen on decaying organic matter. If this opinion should be verified, it is not impossible that we may, through it, find our way to methods of stimulating and controlling the work of preparation which fits the soil to be the food of plants.

We now turn from the geological history of soils to consider some of the more important aspects of their relation to man. We have noted some beautiful elements of compensation or balance which serve to maintain the soils on the earth's surface under conditions which fit them for the needs of plants. But this fitting is for the condition in which the soil is occupied by forests or other luxuriant natural growths of vegetation. When so covered by a mat of verdure the soil tends to maintain itself by the forces brought into operation through the plant life. When man subjugates the soil to the needs of his industries, he is compelled, in most cases, to bring the soil into extremely unnatural conditions. For the greater part of his crops he must strip the surface of verdure, and leave it exposed during the period of the winter season to the action of the torrential rains which usually fall at that time. The important result of this action is to expose the soil to a process of mechanical erosion. We have only to observe the surface in a little field in a time of heavy storm to note that a perceptible portion of its mass is borne away to the streams and thence to the lower plains of the drainage, or, it may be, directly into the sea. In most cases in this country, at least, the surface of our constantly tilled fields is by this action sinking down at the rate of several inches in a century. If the under level of the soil went downward at the same rate as the upper, the result might not be immediately disastrous; we should have in effect only an intensification of that downward sinking of the soil which we have seen to be common to all of them wherever they lie. But in all cases the downward sinking of the surface due to the waste incident to tillage takes place more rapidly than the down-sinking of the lower level. This is due to two reasons; in the first place, the erosion of a

tilled field is practically in all cases vastly greater than the erosion of such a field when forest or grass-clad; next, the removal of the natural vegetation diminishes the down-sinking of the lower level of the soil in two ways. The removal of the plants with strong roots arrests the process of disrupting which they bring about in the under rock. Furthermore, the destruction of the bed of decayed vegetation so characteristic of forests deprives the water of its normal charge of gas, and thus diminishes its influence in corroding the bed-rocks. It may be accepted as a general fact that all ploughed soils whatsoever are diminishing in thickness except so far as the waste may be restored by contributions of matter in the form of manures. It is doubtful if any considerable part of the tilled lands in the world, at least those which are not visited by annual floods, escape a constant diminution in depth.

This evil arising from tillage is in the alluvial lands practically not worthy of note, at least in those portions of such lands as are subjected to annual inundations. It is probable, however, that not more than one-tenth of the soil value of the earth's surface is contained in lands of this nature. The glaciated districts, although they have in general soils of only moderate fertility, are tolerably exempt from the evils we have noted. The considerable penetrability of the deposits to water makes them less liable to wear than the surface of our ordinary fields, and, moreover, the pulverized rocky matter has in most cases a great depth, and if any portion of it washes away it merely lowers the level of the soil. The tiller may be kept busy picking out the large stones, but with labor, even where the soil washes considerably, he can maintain its fertility. It is difficult to determine the proportion of the soil value of the earth which is contained within these glaciated areas, but from

such sources of information which are known to me, I am inclined to compute this area as not exceeding one-tenth of the whole. Thus we have about two-tenths of the soil value of the earth in a shape to be protected by natural conditions from the waste which man tends to bring upon them. The remaining four-fifths of our soil are as far as they have been won to tillage in great danger of destruction.

Unfortunately there are no statistics at our command which serve to show the true extent to which this wasting is taking place. In this, as in many other important matters concerning man's relation to the earth, foresight has not yet been effectively stimulated. Men look upon the earth as in some fashion owing them a living, and with their brutal confidence that it will continue to do in the future the part it has done by them in the past. From some observations which I have made in the State of Kentucky I am inclined to believe that the soils of that area, though on the whole not more ill-used than the average tilled fields of this country, are losing depth at the rate of several inches in a century. In Europe, where the tillage is of more careful character, and where certain precautions to which we are about to refer are taken, though on the whole imperfectly, the rate is less. In Southern Europe, however, since the beginning of the Christian era many regions which were once fertile have by the washing away of their soils been reduced to wastes of bare rock. This ruin has not only affected the tilled grounds of the valleys, but has been even greater on the mountainous uplands which, though of inconsiderable thickness, once bore luxuriant forests. The stripping away of these woods has left the soils a prey to torrential rains: they have been precipitated into the water-courses and swept away

to the sea or lodged on the alluvial lands which needed no such contributions to their fertility.

The present age is marked by a strong conviction that man owes much consideration not only to his fellows, but to the generations to come. With this increase in the sense of duty which men set before their eyes we may hope in time for the most careful preservation of our soils which is consistent with their utilization. We may soon expect to see the law recognize the fact that a man has only a right to use a portion of the earth's surface in such a manner as is necessary for his immediate needs, care being taken that the reversions of the generations to come have been properly guarded. When this view finds fit expression in our laws we may expect certain stern limits to be put to the present reckless waste in the heritage of life represented in our soils. We may expect that all fields from which the soil is likely to be removed by careless tillage will be kept in the state of forest or in grass lands, in either of which conditions they may be maintained in most cases without any perceptible detriment. If such a system were now enforced all over the earth; if, on the basis of well-made surveys, the law prescribed the nature of the care to be taken of areas likely to lose their soils, it is not probable that the result would be any considerable reduction in the amount of food products. A large part of the earth's surface now in the state of forest is of such a character that there is no necessity for that covering in order to preserve the soil from waste. These forest-covered plains, if given to agriculture, would ensure a maintenance of a food supply. Even where the soil of steep hillsides needs to be tilled for certain peculiar crops—as, for instance, for vineyards—it is possible to preserve it from destruction by a system of terraces, returning the waste which

may find its way to the lowlands back to the place whence it came.

In the conservation of our soils we may also expect much from the development of irrigation systems. Such a system, when properly administered, operates vastly to extend the alluvial belt of the rivers by taking the water from the torrents charged with a certain amount of sediment, and distributing it over the surface of the lands in such manner that the silt is retained in the soil. Moreover, the system of ditches and ridges which have to be created on irrigated fields tends greatly to prevent the violent washing of the soil in times of flood.

It is evident that the soil problem, though perhaps the most serious of all the physical difficulties which beset the future of man, is by no means beyond his control. We may find in it a new and nobler field for the exercise of his intelligence and his prescience than he has as yet secured in his careless relations to the earth.

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